SERVO MAGAZINE

November 2004

From HomoSapiens to RoboSapiens

GRASPING UNDERWATER ROBOTICS

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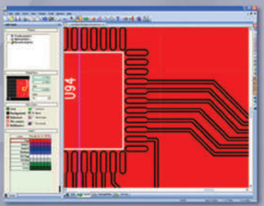

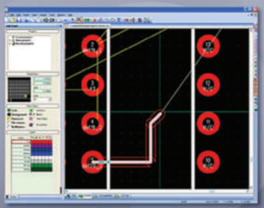

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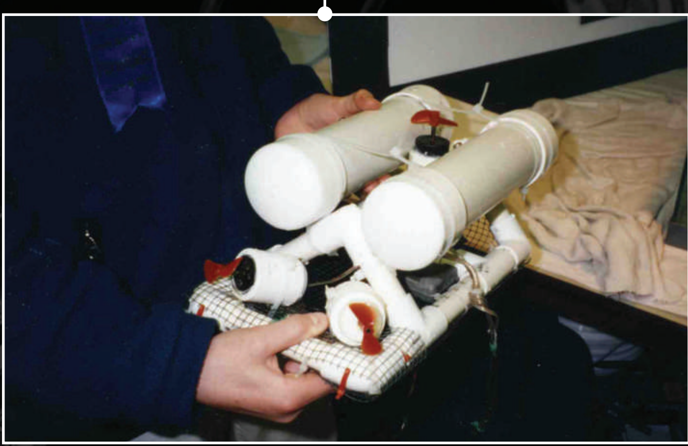
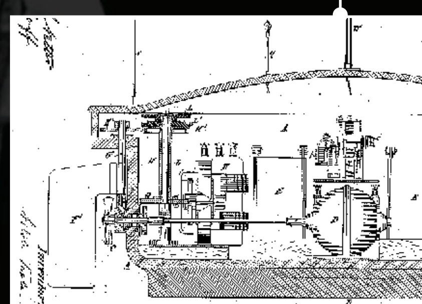
Features & Projects





Mind / Iron

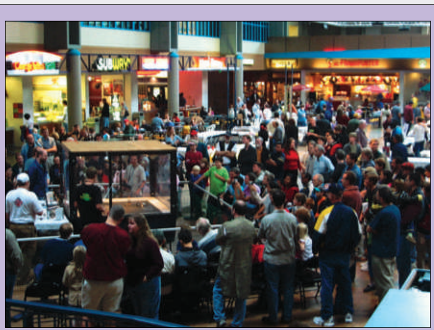
by Dan Danknick

If there is one thing that I keep writing about in this column, it is the need for robotics clubs to spur development by announcing events and to include the community in its projects. I'm glad to say that I watched the Seattle Robotics Society attempt both at their Robothon event, September 25-26. Guess what? It not only worked, but it worked *well!*

At the top of the list at Robothon was the Robo-Magellan event — a scaled down version of the DARPA Grand Challenge — held outside on a giant lawn. (Author and competitor Michael Miller has been writing about his effort in the August-October 2004 issues of *SERVO*.) This is one event that we felt strongly about, so we helped sponsor it. This year, no one managed to finish the course, but a lot of progress was made. I heard Ted Larson from the Odyssey team mumble something about rigging up an ASIC to help him with double-precision floating point math for next year.

Back inside the building at Seattle Center, there were vendors showing off robot parts, BEAM kits, microcontrollers, and DVDs to the general public. As well, there were some really great robot demos going on all of the time: a two-wheel balancer that followed red clothing, a robot that picked up and stacked foam blocks, robots that followed lines — it just kept going on and on. Most interestingly, the builders of these robots were there, happily explaining the operational details to anyone who seemed interested. I noticed a gleam in the eyes of the kids running around (and fear in the eyes of the ones wearing red pants).

Seven teams entered the Robo-Magellan contest — a good showing!



A huge crowd gathered each day at Seattle Center to see the various robots on display.

As evidenced by the Robo-Magellan results, there is still a lot of work to be done on robots that aim higher than the simplest of tasks. Locomotion seems to be squarely in the bag, but sensor tuning and filtering has a way to go, too. Still, this isn't much of a surprise, as our five senses are so radically advanced that roboticists are barely scratching the surface with their electro-mechanical versions.

By the end of the event, I had been asked six or seven times, "So, Dan, what do you think?" I usually answered with something like, "It's great!" Now that I've had time to reflect on the event, I have to say that I think the Age of Robots is upon us! SV

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OUR PET ROBOTS
Guido
Mifune

BIO-FEEDBACK

Dear SERVO,

I built the photovore described in the BEAM article and the Nv neuron, but it didn't work correctly. It stayed on only when IN was connected to Vcc. I searched the Internet and quickly found that the capacitor in the neuron WASN'T POLARIZED, so I substituted a non-polar one and it worked perfectly — as described in the article. I'm not mad — just glad it works, but I would like to know what caused that error. It's still a cool circuit, though.

D. McGrath
via Internet

Congratulations to Daryl Sandberg and Larry Geib for winning the 2004 SRS/*SERVO Magazine* Robo-Magellan Competition. Their autonomous robot navigated the farthest distance at Robothon's diminutive, DARPA Grand Challenge-inspired course.

Tom Gray and Wolfgang Goerlich respond:

Regarding the substitution of a non-polar one — which worked — there are a few things to keep in mind. In the Nv timer project, polarized caps should give good results. We've used tantalum caps and electrolytic caps — both of which are polarized — and they work fine. With a polarized capacitor, you have to pay attention to how it is placed in the circuit. For the Nv in that project, the capacitor's anode (+) goes to the PIC, and the cathode (-) goes to the bias point.

Regarding the statement, "it stayed on only when IN was connected to Vcc," — good observation! All Nv Neurons perform that way. If you let go of the switch, the input is pulled low and the Nv shuts off. You have to hold the switch down (or something else to tie the input high) until the Nv times out. This effect is particularly noticeable with Nvs that have longer time-outs. Since polarized capacitors tend to have a higher capacitance than their non-polarized counterparts, you would most likely encounter this situation with a polarized cap.

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ASK MR. ROBOTO

by
Pete Miles

Q. I have a power supply problem with my robot and I am hoping you can help me. I am using a BASIC Stamp 2 in my robot and it resets from time to time. I know it is resetting because I have an LED that turns on for a second when the power is first turned on. I am using four Sharp GP2D12 infrared sensors with four LEDS to tell me which sensors are seeing the objects. The motors are modified Tower Hobbies TS53 servos. I am using a separate 6 V battery pack for the servos and a 9 V battery for the rest of the robot. I am using an LM2940 voltage regulator to power all the electronics. The regulator is supposed to be rated for 1 amp and, according to my calculations, the total current draw in my robot is around 280 mA — which is well below this rating — but my microcontroller resets from time to time. Some friends told me to put a big capacitor next to the voltage regulator, so I tried adding a 1,000 µf capacitor to the voltage regulator, but that doesn't help. Do you have any other suggestions?

**— Troy
Miami, FL**

Figure 1. Solutions Cubed Easy Roller Motor and Encoder.

A. First off, these Sharp sensors advertise an "average" current draw of about 35 ma, which can be very misleading. I have measured that these sensors have peak current draws of 200 ma when the infrared LEDs turn on and off. With four of these on your robot, they can be drawing up to 800 ma, which can really tax the ability of the voltage regulator to maintain the output voltage to the microcontroller.

I recently had this same problem with one of my sumo robots and found a very simple solution to this problem. Use two different voltage regulators: one regulator to power the BASIC Stamp and the other to supply power for the rest of the robot's electronics. In fact, all you have to do is use the onboard voltage regulator that is on the BASIC Stamp. By doing this, any momentary voltage drops from the sensors and support electronics will only affect those systems, themselves; they won't cause the BASIC Stamp to reset (assuming that the current draw is not high enough to drop the battery voltage below the dropout voltage of the regulator).

When I did this, I connected the Vin pin (not the Vdd pin) on the BASIC Stamp directly to the positive terminal on the 9 V battery and the voltage input pin of the voltage regulator was directly wired to the positive terminal of the 9 V battery. I did this so that the power sources branched out from the battery to minimize voltage drops from the different components in the system.

Q. My robot uses regular R/C car wheels and hubs mounted directly on the shafts of some gear motors I got from Jameco. The problem I am having is that the set screws keep working themselves loose after a couple of days, no matter how tight I make them. Is there anything I can do to keep them in place — other than gluing them?

**— Mark
Minot, ND**

A. Actually, you are on the right track about gluing the set screws in place. It sounds to me like the set screw fits loosely inside the threaded hole in the wheel hub.

When the motor shaft repeatedly reverses directions, it oscillates the forces from one side to the opposite side on the set screw, which slowly loosens it up. Gluing the set screw in place is one of the common fixes for this problem.

Loctite® (**www.loctite.com**) makes a product called Threadlocker that is used to glue fasteners in place. They have many different versions of this product — from low strength, removable adhesives to high strength, permanent adhesives. I would recommend that you use the Loctite 222 general-purpose Threadlocker. It is purple in color, sets up in about 20 minutes, and can fill some fairly large gaps between the threads of the set screw and hub. It is not a permanent adhesive, so the set screw can be removed using regular tools, but it will be a lot "gummier" than without it. Only a couple of drops are needed to "lock" the set screw in place. So far, the tiny 0.5 ml bottle that I have has lasted three years. Loctite products can be found at most well stocked hardware, automotive, and fastener stores. I purchased mine from McMaster Carr (**www.mcmaster.com**) for a couple of dollars.

Another option is to replace your current set screws with "self-locking" set screws. These set screws have a nylon patch on the side that is used to keep the set in place in high vibration applications. You should be able to get the same size self-locking set screws for your hubs, but they are usually harder to find than regular set screws. McMaster Carr will most likely have the size you need.

Q. Do you have any recommendations for a small, low cost gear motor that has a built-in encoder? I am not interested in surplus motors since I want to always know that I can get a new one when I need one.

Cathy Novak
via Internet

A. Solutions Cubed (**www.solutions-cubed.com**) has one of the best deals for motor-encoder combinations — the Easy Roller Motor with the Easy Roller 200 CPR Quadrature Encoder combination. The encoder comes as a kit that is mounted directly on the motor shaft that extends out of the rear of the motor. It took me about 10 minutes to assemble and mount the encoder to the motor. The Easy Roller Encoder is a two channel quadrature encoder that uses a 200 count per revolution encoder disk. Only four wires are needed to use the encoder: +5 V, GND, and channel A and channel B quadrature signal lines. The Easy Roller Motor is a 12 V, 200 RPM gear motor that has a 30:1 gear reduction that can produce at maximum torque of 50 oz-in (at stall). This motor/encoder combination has the ability to monitor 6,000 counts per revolution, which can enable some very precise positional control; $52.00 for the set makes this one of the best low cost, high resolution motor/encoder combinations available.

Q. I would like to know where to go for 0.2" pitch cog belts and pulleys. I would like a supplier that has a mail order catalog, since I do not have a computer or access to the Internet.

— Clint Ramsey
Quincy, CA

A. There are a lot of companies that will sell these parts via mail or telephone. Table 1 contains a list of companies that I have worked with in the past that have printed catalogs you can request. Stock Drive Products, W. M. Berg, and Nordex will have a much larger selection of drive components, since this is their specialty. Small Parts, Inc., McMaster Carr, and Grainger have a smaller selection of 0.2" (1/5) pitch belts and pulleys, but they have a very large selection of other types of parts that can be handy for your other projects. All of these companies take phone orders and I know Small Parts, Inc., takes mail orders.

Company	Phone	Website
Small Parts, Inc.	(800) 220-4242	www.smallparts.com
Stock Drive Products	(516) 328-3300	www.sdp-si.com
McMaster Carr	(562) 692-5911	www.mcmaster.com
Grainger	(800) 323-0620	www.grainger.com
W. M. Berg, Inc.	(800) 232-2374	www.wmberg.com
Nordex, Inc.	(800) 243-0986	www.nordex-inc.com

Table 1. Mail order parts suppliers for cog belts and pulleys.

Q. In the August issue of *SERVO Magazine*, I saw a question from Steve Anderson asking if there were any "free" oscilloscope programs for the PC. In your answer you said, "What you need is a data acquisition system called a PC Oscilloscope, which is not just a program."

I agree that the PC scopes you mentioned are good choices, but — if your budget is limited to zero dollars — here is an alternative that you might try. In the past, I have worked with kids at the high school level and we were able to use a free oscilloscope program to do many "basic" experiments using just the basic PCs in the science lab and their internal, standard PC sound cards. Though there are inherent limitations to this method (For example, you are limited to the frequency response of the sound card "line in" jack.), the display rendered is a good way to view various basic waveforms and the price is right.

A free oscilloscope program (WINSCOPE) can be found at **http://polly.phys.msu.su/~zeld/oscill.html** and at **www.geocities.com/nlradiofm/winscope.htm** If a Fast Fourier Transform (FFT) is more in line with your needs, a free FFT frequency analyzer can be obtained at **www.relisoft.com/freeware/** I hope this information is useful. Thank you for a great magazine. I look forward to every issue!

— Vern
via Internet

A. Vern, thanks for the information. This helps expand all the options people have for using their PCs as alternative, low cost test instruments.

Q. I have used BASIC Stamps (BS2 and BS2P40) to drive servos. On power up, the servo invariably moves or jerks. In some applications, this situation cannot be tolerated. Does anyone have a cure or technique to prevent such unwanted action? Thanks.

— Bill Triplett
Bluffton, OH

A. This is not a BASIC Stamp problem; it's a servo problem. In fact, it is a servo manufacturer problem. I have verified that the twitching on power-up occurs with Futaba, Hitec, Airtronics, Cirrus, Parallax, and Tower Hobbies servos. R/C servos were never designed for robotics or animatronics applications, so this momentary twitch doesn't have any negative effect for their intended uses. With that said, there are a couple things that you can do to work around this problem.

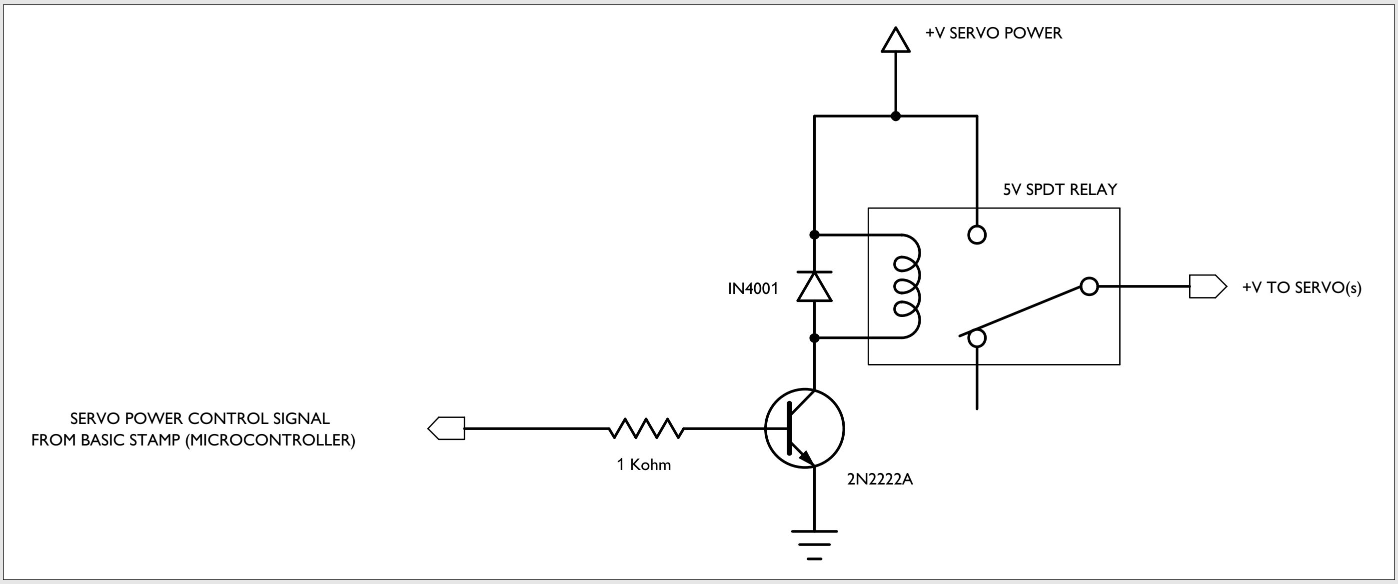
First, you can turn on the power to the servos before turning on the power to the BASIC Stamp and the rest of the system electronics. Yes, the servos will twitch, but — by doing this — the servos will all twitch at one time when you are physically working on the system in a "controlled" environment. If there are any problems that occur, you can shut the system down before the rest of the electronics take control of the system.

The other option is let the BASIC Stamp control the power to the servos. Here, the BASIC Stamp turns the power on and off to the servos. Figure 2 shows a simple, relay-based schematic for controlling the servo power. A power transistor could be used instead of a relay, but any voltage drop across the transistor is reduced voltage (power) to the servos. Make sure the ground wires of the servo power are tied to the BASIC Stamp's ground.

To properly use this approach, you must set all of the servo control signal lines (pins) HIGH right before turning on the power to the servos. Then you bring the signal lines LOW after the power is turned on. Bringing the servo signal lines high before applying the power keeps the servos from twitching.

Then, you can start commanding the servos to their desired positions. I have successfully used this approach for all of my servos, which include models from the manufacturers listed earlier. This method has another advantage: it can be used to turn the power off to the servos when they are not needed. **SV**

Figure 2. Remote servo power controller.



ROBOTS GET WET

Visiting the Undersea World of the ROV

by Edward Driscoll, Jr.

Short of building robots to launch into outer space, the most challenging environment for a machine to function in is underwater. Waterproofing a robot, making it maneuverable via remote control while underwater, and designing it to complete various tasks can be an extremely challenging bit of engineering for any builder — especially when that builder is a student at a two-year community college.

Frank Barrows is a professor at Monterey Peninsula College in Monterey, CA. He teaches two courses there: Automotive Technology and Introduction to Submersible Technology.

For the latter, Barrows teaches his students how to build ROVs, short for Remote Operated Vehicle — underwater robots.

ROVs have gone through some surprising evolutions over the last couple of decades; "15 or 20 years ago, ROVs were built to be sort of ambidextrous and would try to do anything that was assigned to them. Now, builders are finding out that designing an ROV for a particular purpose is a much more effective way of getting something into the water and being successful with it."

These design parameters play a factor in the competitions that Barrows' class enters. They custom design ROVs specifically for the tasks given to them by MATE — Marine Advanced Technology Education Center (**www.marinetech.org**) — which is also located in Monterey and has been sponsoring these competitions since 2001.

Last year's competition involved sending robots to the bottom of MIT's 15 foot deep pool to perform a task that we'll discuss later. This year, the competition was in a pool of equal depth at the University of California at Santa Barbara.

From Barrows' point of view, both competitions were successful exercises for his students. "At MIT, they came away with second place and a highly coveted Most Innovative Engineering Award. This year, they came away with fourth place and three engineering awards. So we feel like we've done well and we'll be looking forward to the next one."

These tournaments present the competing students with some enormously complex engineering hurdles to overcome. The goal isn't simply to build a submersible ROV; it's to build one that can perform a variety of exceedingly complex tasks.

Finding Rusty

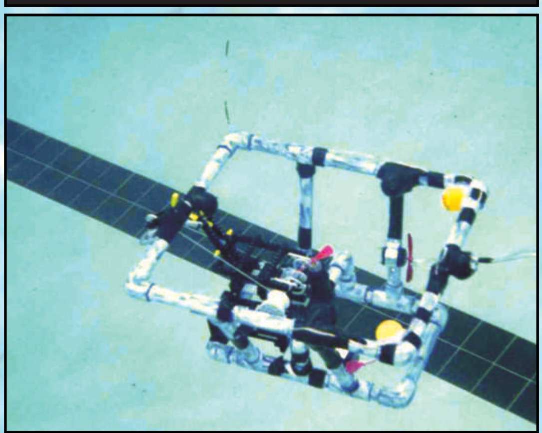
In the first competition that Barrows' class competed in, the mission scenario was that the Titanic had sunk. "And the Titanic, in this case," Barrows says, was, "a PVC framework at the bottom of the pool with some tarps spread over it to represent the bulkheads. There was an opening in the side of it, supposedly for entering a stateroom where — prior to our getting to the area — an ROV had gotten trapped inside earlier."

MIT had dubbed the trapped ROV "Rusty." It was about 24 cubic inches in size and was also built out of PVC. "She was negatively buoyant by about 10 pounds," Barrows adds. The competitors had to design an ROV that would submerge, enter the mock-up of the Titanic, pick up Rusty, and get out of the side of the mock Titanic through a hole that was about three feet square.

The scenario was built around the idea that Rusty's tether had gotten caught on sharp metal edges of the bulkhead and had torn away, causing him to be stuck inside the simulated Titanic. "'Rescue Rusty' was the nickname of the mission," Barrows says, "and we had to design the ROV that would do that job."

The three foot square opening meant that there wasn't much room for error. "In fact," Barrows notes, "we were only one of two teams out of 11 that got the job done at all." Other teams were able to pick up Rusty, but one of the most common failures was that the combination of Rusty and their own ROV became

Underwater robots come in all shapes and sizes. This one has a PVC pipe frame.



THE YELLOW BOOK

The bible for Barrows' class has been a book called *Build Your Own Underwater Robot* (1997, Westcoast Words; **www.westcoastwords.com**), written and self-published by Harry Bohm — a project manager in the school of engineering science at British Columbia's Simon Fraser University — and his co-author — Canadian journalist Vickie Jensen.

Barrows says, "To give you an idea how good it is, we use that book as our textbook for the first year at the school. Harry Bohm came down and helped me put together a curriculum for the first year. In fact, he became so enamored of what it was we were putting together for this kind of class that he actually spent the first two weeks with us in the classroom, just getting a feel for it."

Bohm and Jensen's book is a spiral-bound 8-1/2" by 11" with bright yellow covers. If Barrows has a complaint about "the yellow book," it has to do with its tone. "He wrote that book for junior high school and high school kids. When you read it, you kind of get that idea. However, it has worked out so well for anyone who tackles a first-time ROV project that I would suggest that anyone interested take a good look at it."

One of Bohm's chief suggestions that Barrows firmly agrees on is his choice of a motor for an ROV.

"Waterproofing a motor is probably one of the more difficult tasks to go around. If you pick a motor that's not waterproofed and then you decide that you need to encapsulate it somehow in order to keep it dry, it's not an easy task."

In contrast, it's easy to keep a camera dry, Barrows notes. There are no moving parts between the inside and outside and all you have to do is put enough epoxy around it to seal it off. However, "the problem with most underwater motors is the rotating shaft. So most folks go to some kind of motor that's already been designed to be waterproof. One good selection is a bilge pump motor. It's already been designed to work in a boat."

Barrows says that his class typically installs 12- to 36-volt bilge pump motors, "right out of the West Marine catalog. We chop them apart, throw away the impeller, and use hobby shop R/C boat propellers. In the last two years, we haven't lost a single motor."

The bilge motors aren't the only part of an ROV that Bohm designs to be as rugged and simple as possible. He doesn't use complex electronics to control the ROV; instead, he recommends double-pole, double-throw switches to deliver — usually — 12 volts DC in one direction to make the motor spin and then — by flipping the double-pole, double-throw switch the other way — reverse the direction of the motor.

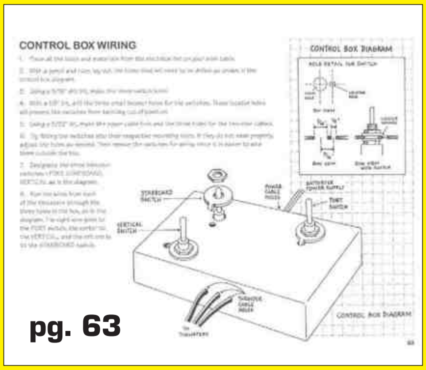
Bohm doesn't get mission-specific; the goal is to simply get an ROV with a camera that will get in the water and look around. Barrows says that, if he were rewriting the book, he'd be tempted to add, "a manipulator arm or some sort of tool to do a job."

Still, Barrows says that lack of one is okay; the chief objective of many ROVs is to simply look around.

As an example, he mentions that, when law enforcement officials need to find a dead body underwater, they typically drop a sonar towfish first (the same underwater device the competition at UC Santa Barbara was built around). Very often, though, it simply returns shadows. "It's very rare that you get a clear enough image to be able to tell that it's a human body, especially if it's been down there very long."

Today though, there's an alternative to immediately suiting up a diver to verify sonar. An ROV with a camera is frequently dropped into the water instead.

"So, eyeball ROVs are very common. That's the level that Harry takes you to in his yellow book and I would suggest that anyone take a close look at that to see if — maybe just by reading it — you'd be ready for the next level or if, maybe, it's challenging enough to be a first time operation."



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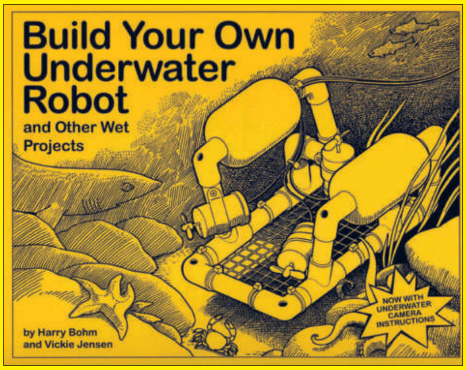

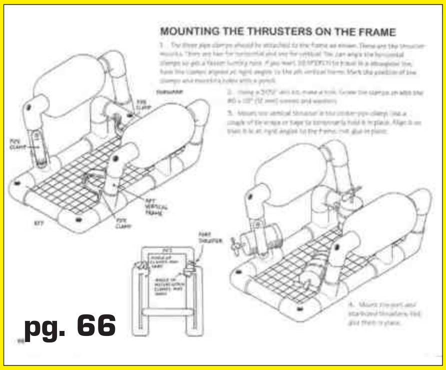

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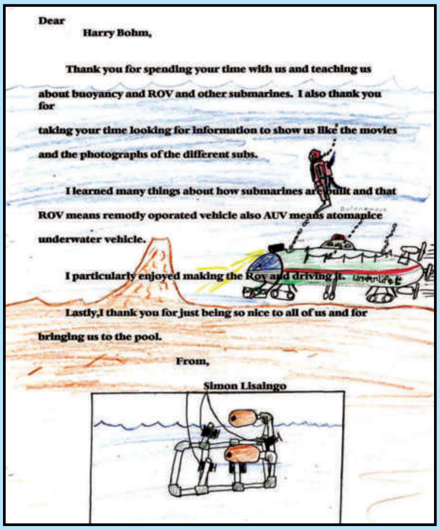

Dear
Harry Bohm,

Thank you for spending your time with us and teaching us about buoyancy and ROV and other submarines. I also thank you for

taking your time looking for information to show us like the movies and the photographs of the different subs.

I learned many things about how submarines are built and that ROV means remotly oporated vehicle also AUV means atomapice underwater vehicle.

I particularly enjoyed making the Rov and driving it.

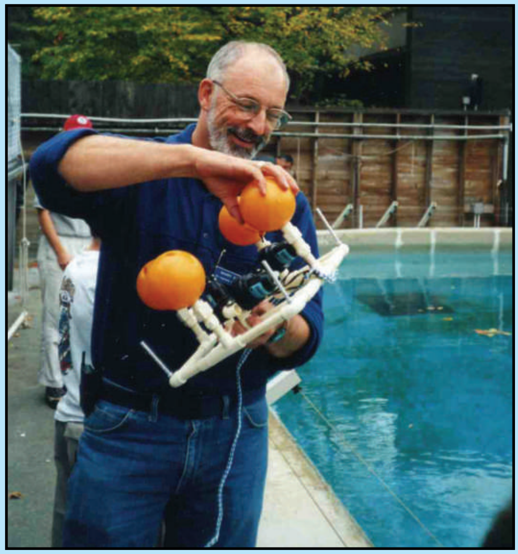
Lastly,I thank you for just being so nice to all of us and for bringing us to the pool.

From,

Simon Lisaingo

Student letters testify to the delight of tours by SFU's Underwater Research Lab.


Harry Bohm works with a student at an ROV workshop at the Vancouver Maritime Museum.


Bohm secures the orange floats used for buoyancy prior to launching an ROV.

too big to get out through the small opening. "There were lots of other problems and lots of other failures, but it made us feel pretty good that we could get the job done at all."

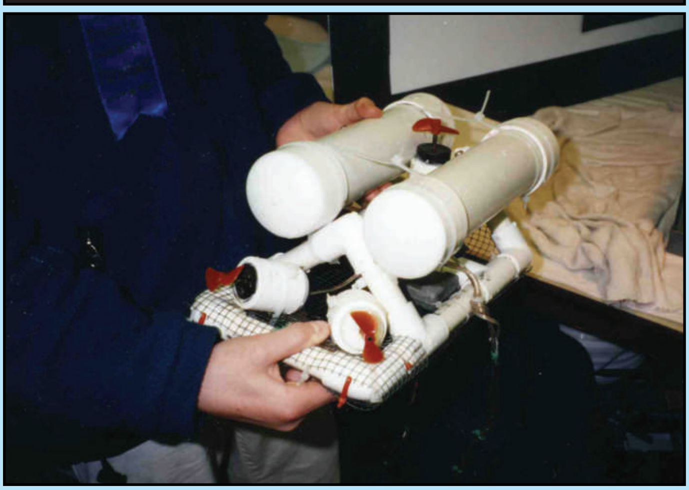
Run Silent, Run 15 Feet Deep

For this year's mission — held in a UC pool in Santa Barbara — Barrows' team designed two ROVs. "The scenario was that a German submarine had sunk on a coral reef off of Florida and there were toxic chemicals aboard the submarine, in its reservoirs." To make that scenario even more complex, the imaginary researchers who discovered the submarine had lost a sonar towfish — an underwater device that is dragged behind a surface vessel to return a clearer sonar picture to the person who sits behind the sonar's CRT screen in the boat above. Complicating that scenario is another piece of advanced underwater technology: a pinger — an electronic tracking device that scenario imagined was tossed into the water by a member of the ship's crew when their towfish got hung up on the reef.

That's one complex scenario! To complete it, the ROV teams had to perform seven tasks. "We had to recover the towfish and the pinger. We had to identify the submarine via its ship's bell that was also on the reef someplace. We had to try to get a sample of this toxic material that was in the submarine's reservoirs. We had to measure the length of the submarine to help identify it and also measure the depth that the submarine was working at.

"Oh, and there was a time limit of half an hour." No wonder Barrows' team decided to build two ROVs to tackle it. Even with two machines, though, it ended up being too complex of a mission for any of the student teams to complete. "This year, no one got all seven jobs done. A number of them got four and I think the winner got five."

This student-designed ROV took first place at a regional science fair. It uses PVC tubes and end caps for buoyancy.



A plastic tub becomes a test tank as teachers try out the Sea Perch ROVs they just completed.

A teacher builds his first underwater robot at a workshop for educators.

Co-author Vickie Jensen demonstrates how to build a simple diving bell.

ROV EVENTS FOR STUDENTS AND TEACHERS

The Marine Advanced Technology Education (MATE) Center in Monterey, CA, provides great support and resources for ROV education. Contact Outreach Director and Competition Coordinator Jill Zande (jzande@marinetech.org) or visit the website (**www.marinetech.org**) for information on the following:

- Regional ROV competitions for students in the US and Canada.
- 2005 National Student Underwater Robot Competition, co-organized by the Marine Technology Society's ROV Committee.
- MATE Summer Institute for Faculty Development, held each summer in Monterey.

MATE is also working with Harry Bohm, Vickie Jensen, and Dr. Steve Moore to produce an expanded handbook — *Introduction To Underwater Vehicle Design*.

Get Wet, Young Man

MATE's competitions herald an impressive future for ROVs. In 1865, when asked where opportunity lay, Horace Greeley wrote, "Go west, young man." Today, he might be telling that same young man that the future is of a more aquatic nature. Barrows says, "One gentleman explained it to me this way: Imagine that you and I are back around 1925 and we at a county fair with our first opportunity to see a biplane come somersaulting through the air — what we used to call barnstorming. We're sitting there, saying, 'What's going to happen in 75 or 100 years? Where will these machines be?'

"I think that, if we sat down and tried to guess all of the things that ROVs — or similar equipment — are going to be doing in 75 years, we would be very short-sighted in picking up all the things that are going to happen. Beside farming the ocean, there are the scientific aspects: medical research and feeding our expanding population."

Echoing the thoughts of science writers — like Arthur C. Clarke — who view the potential of the sea as being on par with space research and development (and both involving pitiless hostile environments), Barrows is predicting a similar future for exploring and exploiting the sea.

"We're in about the same era as those biplane pilots. Underwater exploration and ROVs have been around for a while, but not at today's level. Right now, we're really getting good at exploring the ocean and exploiting it for human purposes, for lots of reasons.

Barrows predicts that ROVs will allow cost effective exploitation of resources underwater, such as oil, gas, and minerals. "All of a sudden, people are going to find that it's cost effective to recover the manganese modules that are down there — or any one of a zillion chemicals that the ocean is full of — because we haven't reached the absolute cost effective need to take advantage of it.

"So where are ROVs going to go? Beyond any of our wildest dreams."

Get wet, young man. **SV**

Luke Powell concentrates on wiring a control board for an underwater robot.

Launch time for an enthusiastic underwater robot workshop group at the Vancouver Aquarium.

FIRST FRENZY 2004 PART 3

BY EVAN WOOLLEY

Welcome to the third installment of Team 1079's second FIRST experience. This month, will cover the rest of the FIRST build-up to the competition. You've already been introduced to two team members — Bryce Woolley and Justin Lyons — and this article will come from the perspective of another team member.

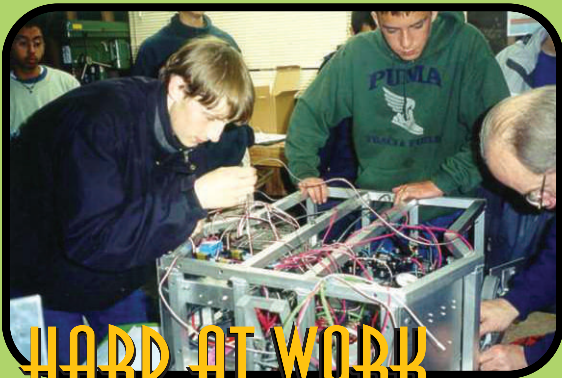
I'm Evan Woolley, twin brother of Bryce and co-captain of Team 1079. I'm a senior at Chaparral High School and have been involved in FIRST for two years. This article will focus on Team 1079's trials and tribulations during the six week build time, while addressing some parts of our team dynamic that most all FIRST teams know about and other aspects that make us unique.

While Justin's group took care of the arm project, my dad, myself, and other team members worked on the frame and drive train. Inspired by other designs last year, this year our team wanted to build a four motor drive train with the two Bosch 1/2" drive

Standing, from left to right: Bryce Woolley, Jairus Ciocon, Bryant Nelson, Kristen Baber, Justin Lyons, Ryan Potts, Jack Gordon. Kneeling: Evan Woolley.

Team members not pictured: Evan Heid, Josh Larsen, Austin O'Neal, Ivan Hoffman.

CLUB CREATE



HARD AT WORK

cordless drill motors and the two CIM motors supplied in the kit. This year, the FIRST kit of parts contained 11 motors, though never more than two of any type.

Quite a bit of flexibility is allowed in extra parts choices for the robot, with the main exceptions being the motors and the control system. Only the motors supplied in the kit and the complete control system from Innovation First can be used on the robot.

Another limitation, at least for our team, manifested itself in the extensive safety regulations required by FIRST concerning the electronics. All of the powerful motors were required to use breakers and Victor 884 speed controllers. Safety is a good thing — don't get me wrong — but our team was tight on resources. The kit only came with enough Victors for the four strong motors that comprised our drive train and we couldn't afford to buy any more.

The kit came with plenty of Spike relays for the lesser motors, but it limited us, nonetheless. Basically, our quest for a strong drive train eliminated our hopes of a hanging mechanism. Hanging would require more strong motors, which would require more Victors, which would require more money. We didn't have any extra money, so no hanging for us. The team was, nevertheless, satisfied with our design, though it's not like we had much choice.

Another motivation for this design was that we thought it would be sturdy and reliable; one of our main goals was a robot that drives — and drives well. The same basic principles that apply to all other areas of robotics apply in FIRST, too: If you want to even have a chance of doing well, you need a reliable drive train.

This point was even more important to us, due to our rookie season experience last year. Our robot last year had a great design for the game and looked cool, though we had built the robot in such a way as to render it almost impossible to work on. So, in keeping with Murphy's Law, we naturally had to work on it to rectify some of our "rookie" mistakes. This led to our robot sitting in the pits with our hands inside of it instead of playing the game on the field. We learned from our mistakes and we were darn sure that — this year — our robot was going to be running for every match!

Our first idea was to pair the motors in a custom gearbox, but — when we found out that such a design would come with a price tag of $500.00 — we decided to look for more affordable alternatives. This year, our team was on a very tight budget, so we had to get creative with some of our designs.

A side note here: Another great aspect of the FIRST program is that all teams across the country freely and gladly share any design ideas that they develop. Many of the teams have been in existence for a number of years and have an extensive engineering base filled with some of the sharpest engineers from some of the largest companies in the country. These brilliant minds come up with some really cool ideas — some of which are very tricky, multiple motor gearboxes — but, alas, it was not meant to be.

A visit from one of our esteemed, professional engineering mentors proved fortuitous, though. He suggested using four smaller wheels instead of the two larger wheels. This was a great idea for several reasons. First, this made it so that not having a gearbox was no longer a problem — with two smaller wheels, we could just match them closely with sprocket arrangements and dial them in through the programming. Second, that same mentor said he would donate the wheels — FREEBIE! Lastly, this new design was far cooler than the old one.

Everyone agreed to this plan and it kept with our design motto: "Keep it simple, dadgummit!" We used the Bosch motors with their stock gearboxes locked in low by means of a custom machined internal spacer ring. These powered the front wheels via a pair of sprockets and #35 chain at a 1:1 drive ratio. The CIMs or "Chips" drove the rear drive wheels through a double chain reduction arrangement with both #25 and #35 chains and sprockets being used. This resulted in a very close match between the front and rear drive wheels.

We were able to borrow a stroboscope from Cosworth Racing to allow us to check the individual wheel speeds very accurately and then adjust them through the program. As was mentioned earlier, the complete control system is supplied by Innovation First. The system is comprised of the robot controller, the operator interface, a pair of RS-422 radio modems, and a pair of multifunction joysticks.

The robot controller contains two Microchip PIC18F8520 microcontrollers, the master processor, and the user processor. The robot controller has 16 analog inputs and 18 digital

BILL & MODOS

input/output pins, as well as 16 PWM and eight relay outputs. The controller is programmed in C to take full advantage of the flexibility of this powerful unit and a default program is available to all teams on the Innovation First website to provide a great base to work from.

By the middle of the build, things seemed to be moving along smoothly. Justin, Jack, and Bryant were making good progress on the arm, Bryce was forging ahead on the pneumatic kicker and goal grabber, and the drive train was agreed upon. Despite all of this progress, we really didn't have anything to show for it. Why? Because our floor hadn't arrived yet!

The first two weeks were devoted to finalizing a basic design for our robot so that we could draw out a floor design to be machined at our local sponsoring machine shop — Flashpoint Machine. Our build was centered around the floor. We designed the floor in such a way that it already had most of the attachment holes, so — theoretically — we could just throw the robot together once we got the floor back. (Not that we would actually throw it together — we do take a lot of pride in our work.)

The first week of our build was devoted to finalizing the floor design so that it would be easy to build the rest of the robot right on top of it. Why do these guys put so much effort into the floor, you ask? Our obsession with making a perfect floor may come from our background in combat robotics.

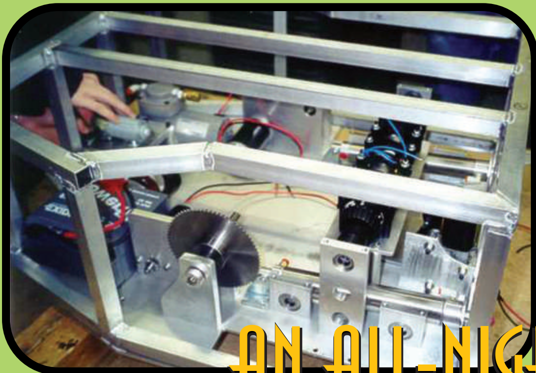
KRISTEN & MODOS

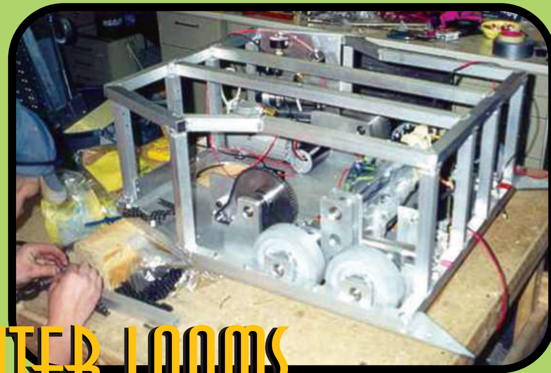
In combat robotics, the floor is an ideal mounting place to keep things safe because it is robust and rigid. Combat robots need to have robust floors because you never know when a saw or something of the like can get a shot at your underbelly.

While there are no saws in FIRST, the same basic design principles apply. We use our floor as a primary mounting point and we know that everything we attach to the floor will stay put. Additionally, since the floor is drawn on AutoCAD and all of the bearing block mounting points and motor mount locations are precisely situated, everything is in the right place. Mechanical losses due to inaccurate placement of driveline components are eliminated, thus allowing the available power to be properly utilized for desired motion instead of overcoming poor construction.

Unforeseen difficulties at the machine shop, however, delayed the completion of our floor. I'm sure most people (especially FIRST teams) can relate to the frustration of late parts. We weren't going to give up hope, though.

Week four and still no floor. It was starting to look like some of the team members' wishes for some all-nighters would come true. One bright spot was the arrival of our frame, custom welded by a friend at Cosworth Racing. Our frame was also heavily influenced by Cool Factor Engineering. Instead of doing things the easy way and just making a frame box, we angled in the sides so our cool four-wheel drive train would show. As you can see, "Keep it simple, dadgummit!" and Cool Factor Engineering sometimes butt heads. When that happens, we go with the





AN ALL-NIGHTER LOOMS

Cool Factor!

An interesting note about our frame is that this is the first time our team had an actual frame. All of the other robots that I've built — including combat robots — have had exoskeletons. Why? For one, exoskeletons are cool and I think that they are easier to work with. Even though what we had this year was the closest thing to a frame that we've worked with, we still used it essentially as an exoskeleton.

The main things that attached to our "frame" were our body panels. Our frame didn't serve as a major attachment point for anything because everything was attached to the floor. There's another advantage to our floor efforts — it keeps everything very clean inside. Team 1079 takes pride in the look of its robots, inside and out. Our robot this year was constructed entirely of 6061-T6 aluminum and looked great while being quite robust.

Week five and the floor was finally done! The team knew that Flashpoint Machine would come through. With one week until the sectional — an annual practice competition held by Team 22 at Chatsworth High School a couple of days before the ship date — we had a lot of work and a few long nights ahead. Back at Robot Central (the Woolley's garage), we really got to work. The drive train was the first to go in and then we put in as many other things as we could before attaching the frame. Things were shaping up a little too slowly and an all-nighter was looming, but the team was ready.

All-nighters are double-edged swords. Sure, there are a lot more hours to work, but the question is, how long until you become useless? Things start to get sloppy the later (or earlier in the morning) it gets and the team members rely on humor to conquer the desire for sleep. All-nighters (with our team, at least) are where ideas for squirrel-powered robots start to surface, especially when wiring for the drive train is taking so long. (Don't call PETA; we never had to resort to testing this idea.)

On one of our late nights, we were visited by a potential sponsor, Mr. Peter Fiori of Marine Dynamics Corporation. For our team, fundraising doesn't stop when the build begins and Mr. Fiori had seen one of the several newspaper articles on our team in the local paper. He came down to see us in action and he was impressed.

He said he, "was so delighted to see young people spending their weekends and evenings working, building, and learning instead of out, getting into trouble." It was also quite apparent that all of us were having a great time. Marine Dynamics became our second biggest sponsor and the team was very grateful for his contribution. On another late night, our team was visited by the new principal of our high school. We hoped it might lead to some more school support.

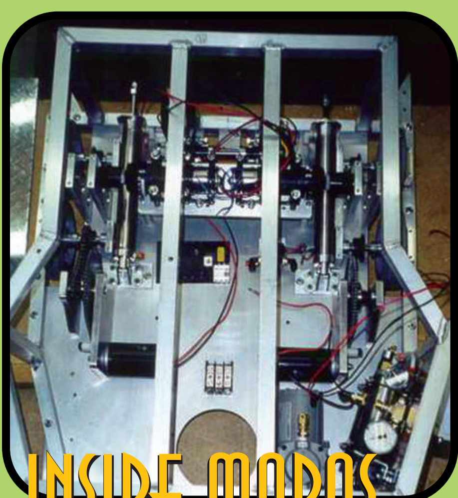
One important dynamic of our team that you have probably picked up on throughout these articles is that we are perfectionists.

Actually, a better way to describe it would be that we take pride in our work. In the opinion of many of our team members, our work is a reflection of who we are and we want to put forth a good image. Not only that, but we are learning skills that will help us in a professional engineering setting, which many of us are planning to go into.

This is quite evident in how we wire our robot. We make a point of taking the time to do the wiring right, with everything neatly run and well labeled. This allows quick repair or replacement of components and aids in troubleshooting, since time is at a premium in that situation.

As was mentioned earlier, FIRST has very strict rules regarding electrical system safety and supplies all of the teams the parts they need to do the job right. The power source for the robot is an 18 Ah, 12 volt SLA and a small 7.2 volt NiCad pack utilized by part of the control system. A 120 amp main breaker that also acts as the on/off switch for the robot controls all power. Additionally, 40, 30, and 20 amp automatic re-setting breakers are used for the motors and other loads. This is a definite change from my brother's and my combat robots, as we do not use breakers in them. In FIRST, if you trip a breaker, you may lose some points; in combat robotics, you would lose some pieces!

By the end of the build, all of the



INSIDE MODOS

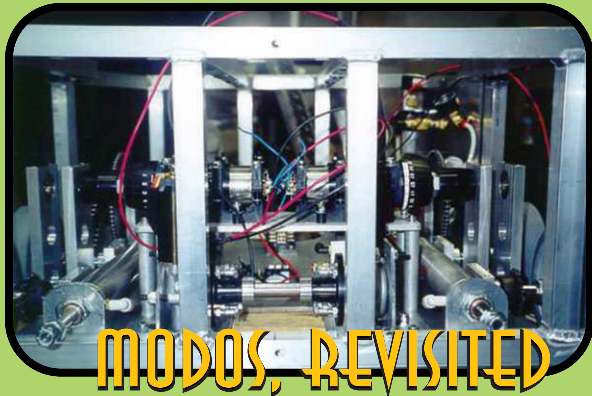
systems were coming together. For one, the Great Music Controversy seemed to reach a compromise. The Kingston Trio reigned supreme on Saturday mornings, mostly due to the fact that most of the team wasn't there that early. Later in the build, on weekday afternoons (and evenings), Metallica had its way, mostly due to the absence of the pro-Kingston Trio element. The bulk of Saturday and Sunday were up for grabs, though, and — since the Trio and Metallica were diametrically opposed — a compromise had to be reached. The final decision was for Boston. Everyone liked it and — let's face it — it's just good music.

The robot was looking good, too. The arm mechanism looked great and our drive train seemed to be in order. The pneumatic kicker and goal grabber were also near completion. Some out there may ask, why the pneumatic kicker and goal grabber? It doesn't seem like they'll give you much of an advantage, so why bother?

The FIRST kit offers a variety of systems, including pneumatics; this option took hold in our minds during the SCRRF robotics workshops held the previous November. A number of years ago, the Southern California Regional Robotics Forum (SCRRF) was formed to help all teams in the area and to expand the FIRST program. One of the many great activities that SCRRF organizes is the annual robotics workshop day at California State University at Northridge.

This day is a great opportunity for all teams — especially rookies — to get familiar with the systems that the robots may utilize, as well as other aspects of building a successful team. The word "may" was used on purpose, as the game changes every year, so no one knows what will really be necessary until the kick-off morning.

One of the SCRRF classes was on pneumatics and many of the club members who attended that class wanted to apply their new knowledge. The pneumatics kit is quite complete, including a small, 12 VDC air compressor, two cylinders, various single and double solenoids, two storage tanks, pressure regulators, and a bunch of fittings and tubing.



The pneumatic kicker was a good thing to experiment on because it wasn't critical to the success of the robot, but — if it worked — it would ratchet up the Cool Factor. The same idea applied to the grabber, even though it was electric, not pneumatic. This also gave the team a chance to use a variety of different systems and learn a lot.

At the end of the build, everyone was satisfied with the final product — Modos. In its finished form, our robot utilized seven motors and a fully functioning pneumatics system. One of the final touches was the sail. We've gotten a lot of questions about it. The original purpose was — you guessed it — to look cool. It was much more aesthetically pleasing than a bare mast and it was a good place to put our logo.

Another final touch was all of the stickers from our sponsors. We truly appreciate the support given to us by our sponsors and we think a little bit of recognition through a sticker on the robot is the least we could do. All of the stickers also reveal some of the influence that professional racing has had on our team.

Also, as a strange side effect of the great number of stickers on the sides of our robot, the sail actually ended up having a purpose. All robots are required to have their team numbers on all sides. Since the stickers took up all the room on the sides of the robot, the sail served as the perfect spot to put the team numbers. Cool Factor Engineering can be practical!

In the end, everyone was thoroughly pleased with their efforts. Be sure to catch the final article next month to see how we did in competition! SV

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Getting Up to Speed With PWM

If you have been around the hobby robotics world, you probably noticed that almost every robot that you see uses hobby servos for just about every sort of movement. Whether it is to drive a wheel on a mobile robot, change the angle of something, or position a grabber arm, it will likely use a hobby servo. Hobby servos are useful devices, but they are not the only way to get things done in robotics. Along with hobby servos come a list of drawbacks, such as slow speed, little variability in speed, and the need to constantly send pulses to them so that they maintain speed or position. Last month's column talked about using Pulse Width Modulation (PWM) for audio purposes. This month, we'll go over how to use PWM to control DC motors.

Before discussing PWM, let's look at another way to control the speed of a DC motor. This would be to vary the current that is passing through the motor. While this is a valid way of controlling the speed of a motor, it is fairly inefficient and not very robust. Take a look at Figure 1; the current going through the motor can be adjusted by varying the position of the potentiometer. Let's pretend that the motor is just a resistor with a value of 30 Ω. In reality, the effective resistance of a motor will be lowest when the motor is stalled and highest when it is running at its top speed with no load placed on it. If you are dealing with a low enough voltage, then you can get away with this strategy.

For example, if you are running your motor at 5 volts and you have the potentiometer adjusted to 20 Ω, you will be dissipating 0.2 watts through the potentiometer. As the voltage goes up, the wattage through the potentiometer goes up with the square of voltage increase. This means that, if you increase the voltage to 10 volts, the wattage dissipated through the potentiometer jumps to 0.8 watts. If you happen to be using an inexpensive potentiometer from RadioShack, then you are just 0.2 watts shy of its rated limit. The potentiometer that you are using will start to become warm with this much wattage. Limiting the current through a motor is a quick and dirty method to vary the speed of a motor. It will work for small motors at low voltages.

In a similar vein, you can vary the speed of a motor by varying the voltage that you drive it with. One way to do this would be to use a variable voltage regulator. This method also suffers from overheating issues if your current draw is sufficiently high. This can be a slightly better method of varying the motor's speed because — to some extent — the overheating issue can be dealt with by using heatsinks on the voltage regulators.

While both of the previously mentioned methods of varying a motor's speed work, they have big problems with overheating and, because of that, they are also inefficient. This is where PWM comes in. With PWM, you are rapidly giving the motor power and then shutting off the power over and

Figure 1. Controlling a motor's speed by using a potentiometer.

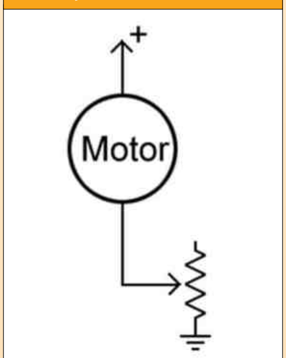


Figure 2. Controlling a motor's speed using PWM.

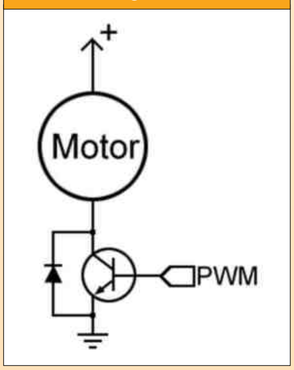
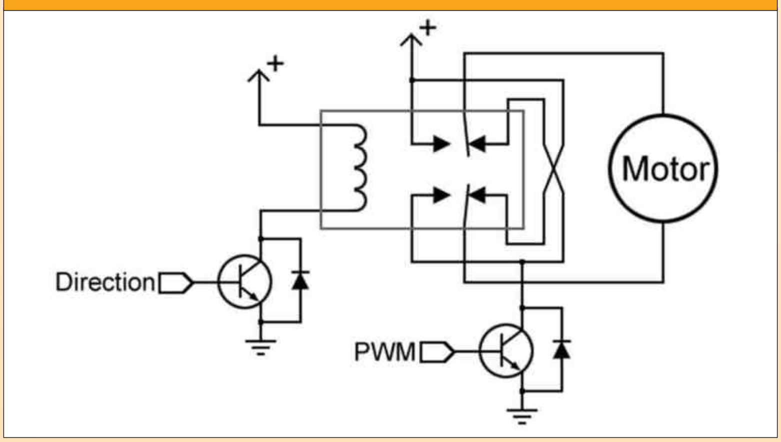


Figure 3. Reversible speed controller using a relay.



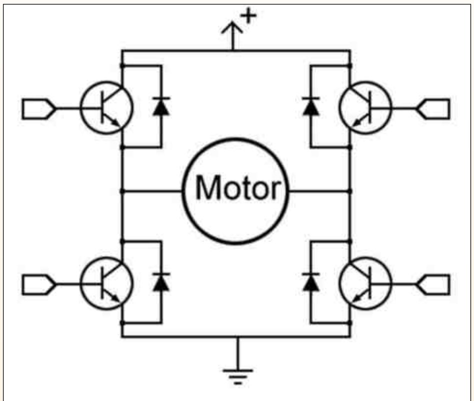


Figure 4. An H-bridge.

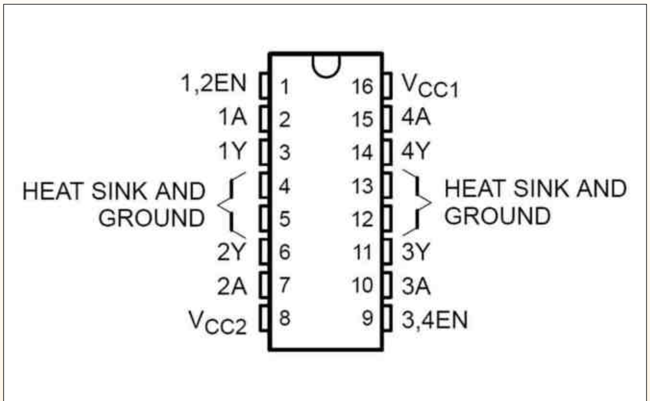


Figure 5. Pinout for the L293D.

over again. The amount of time that you have the motor on verses off determines the average speed of the motor.

Figure 2 shows a simple circuit that you can use to vary the speed of a motor using a transistor to switch the motor on and off. Notice that the transistor has a diode across its emitter and collector. When you are running a motor, you are giving power to its coils in sequence. As you give power to a coil, a magnetic field appears around that coil. When you remove power from the coil, the magnetic field collapses and this sends a pulse of power in the opposite direction that it originally came into the coil. The diode is there to route that pulse of power back to the battery, where it won't damage anything. The relay also has a diode for the same reason.

One thing to pay attention to here is that you need a "fast" diode. The pulses of power coming out of the relay or motor are incredibly short in duration, but can be pretty destructive. Schottky diodes are usually the type used to prevent these pulses from damaging the transistor or FET in speed control circuits.

Varying the speed of a motor in one direction is useful for some applications, such as driving a fan or a water pump. For most robotic applications, you will want to be able to reverse the direction of the motor, as well as vary the speed. One way to accomplish that is to use a transistor and relay, as shown in Figure 3. In this circuit, the relay switches the motor's direction.

Switching direction with a relay is a fairly robust method of controlling a motor's speed and direction. It is easy to build and is inexpensive. The down side of using this method is that it is not solid-state, so the relay will have to be replaced from time to time if it switches often enough. Relays do not switch instantaneously. They can take anywhere from 0.5 to 30 ms to switch. If you need your motor to be able to switch direction rapidly, you will have to choose a relay that can switch quickly.

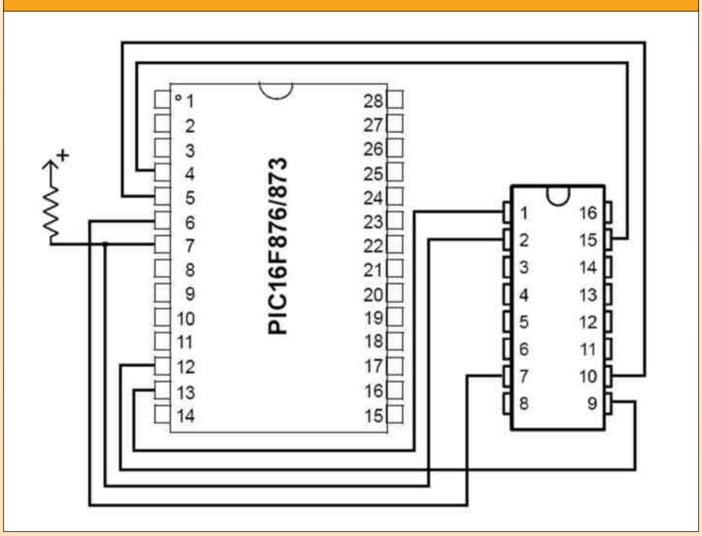
One further drawback to using relays is that they have different specifications for how much current they can carry as opposed to how much current they can switch. Often, you will find that a relay can only switch 10% of the current that it can handle continuously. This is due to arcing between the contacts, which can slowly erode them or destroy them in one big flash if you try to switch them while they are carrying a decent amount of current!

A solid-state circuit able to switch a motor on and off — as well as reverse its speed — is what is known as an H-bridge. An H-bridge is four transistors or FETs arranged as shown in Figure 4. By switching on the transistors or FETs in opposite corners of the H-bridge, you can cause the motor to run. If you turn off those transistors or FETs and turn on the other two, the motor will start running in the opposite direction.

One additional thing that you can do is turn on the two top or two bottom transistors or FETs at the same time. This causes the motor's leads to be shorted together and will cause the motor to resist movement without your circuit having to provide any power to the motor. You can really see this with a geared motor. Try turning the output shaft with your fingers and then shorting the two motor leads together and turning it again. You should see a noticeable difference.

H-bridges are great little circuits, but they are not something that is easily designed. While this column treats them as digital circuits, they are definitely NOT digital and sit squarely in the realm of analog electronics. It can be a very frustrating experience to try to design your own H-bridge unless you have a solid foundation in analog electronics. Luckily for the robotics hobbyist and professional engineers alike, there are pre-made H-bridges on single chips or on circuit boards that you can buy. Some examples are the L293,

Figure 6. Connecting an L293D to a PIC16F873 microcontroller.



TECH TIDBIT

The term Hi-Z is just a fancy way of saying that an I/O pin is for all practical purposes connected to neither the positive voltage nor ground. It is as if there is no connection at all.

L293D, L298, and LMD18200. This column will discuss the L293D. It is the least expensive of the three chips and can carry the least amount of current (600 mA). It is sufficient though for small gear motors.

The L293D is a dual H-bridge that has built-in diodes to catch the reverse voltage spikes that were mentioned previously. Figure 5 shows the pinout for the L293D.

The L293D has three input lines for each H-bridge. There are two inputs that directly correspond to the two outputs. If one of these pins is set high, the corresponding pin will be set to your motor drive voltage. If you input a low signal, then the output pin will be set to ground. The third input line is the enable line. If this line is high, then the outputs will be as described above. If the enable pin is driven low, then the output pins will go high. In Figure 6, the L293D's enable lines are connected to the PIC16F873's PWM output lines. By using these peripherals, you will be able to control the speed of motors connected to the L293D chip.

Figure 7. Code to drive a two-wheeled robot using the L293 and a PIC.

```
// PWM01.c
// This program is a demonstration program for a two-wheeled robot. It slowly
// accelerates the robot forward and then slows back down to a stop. It then
// turns and backs up.
// This program compiles with the CCS C compiler and is meant to be run on a
// PIC16F873 with a 20 Mhz oscillator.

#include <16F873.h>
#device adc=8
#use delay(clock=20000000)
#fuses NOWDT,HS, PUT, NOPROTECT, BROWNOUT, LVP, NOCPD, NOWRT, NODEBUG
const int8 forward =    0b00100100;
const int8 backward =   0b00011000;
const int8 right =      0b00101000;
const int8 left =       0b00010100;
#byte portA = 5

void main()
{
int i, PWMvalue;

    setup_adc_ports(NO_ANALOGS);
    setup_adc(ADC_OFF);
    setup_spi(FALSE);
    setup_timer_0(RTCC_INTERNAL|RTCC_DIV_1);
    setup_timer_1(T1_DISABLED);
    setup_timer_2(T2_DIV_BY_16,63,1);
    setup_ccp1(CCP_PWM);
    setup_ccp2(CCP_PWM);

    portA = forward;
    // slowly ramp up over five seconds
    for(i = 0; i < 255; i++)
        {
        set_pwm1_duty(i);
        set_pwm2_duty(i);
        delay_ms(20);
        }
    // slow back down over five seconds
    for(i = 255; i > 0; i—)
        {
        set_pwm1_duty(i);
        set_pwm2_duty(i);
        delay_ms(20);
        }
    // turn
    portA = right;
    set_pwm1_duty(255);
    set_pwm2_duty(255);
    delay_ms(700);
    // go backwards
    portA = backward;
    delay_ms(2000);
    // stop
    set_pwm1_duty(0);
    set_pwm2_duty(0);
}
```

Figure 7 shows a simple program that can control two motors for a robot that drives using tank-style steering. The program will cause the robot to slowly speed up until it reaches top speed, then slow back down to a stop, turn at full speed, and then go full speed backward before stopping. This program is made to compile in the CCS C compiler for a PIC16F873 with a 20 MHz crystal.

The way that the microprocessor is connected to the L293D in Figure 6 allows the motor to go in either direction or coast. This type of PWM is called "sign magnitude." This is not the only way to do PWM, though. There are two other types. One type is called "locked antiphase." This type of PWM keeps the enable line high and rapidly switches the direction that the circuit is trying to drive the motor. If you do this fast enough, the amount of time that you are driving it clockwise versus counter clockwise determines both the speed and direction of the motor.

There is one more way to control a motor through PWM. This method alternates between driving the motor and shorting the leads of the motor together to act as a brake.

Figures 8 and 9 show how the L293D could be set up to use these other two types of PWM. To drive the circuit in Figure 8, just send a PWM signal out to the H-bridge on the line corresponding to the motor that you want to control. To drive the circuit in Figure 9, you would have to do your PWM in software, since you would need to be able to hold one input for the H-bridge low and send a PWM signal to the other input. This would drive the motor in one direction. If you wanted

the motor to go the other direction, then you would want to hold the second pin low and send a PWM signal to the first pin.

You may be asking yourself right now why you would want to use one type of driving an H-bridge over another. The first method — where the motor is either driven or is coasting — is easy to set up a circuit for if you are driving a motor in only one direction. It also requires no extra circuitry when connecting to an H-bridge that has an enable line. The down side of driving a motor this way is that it is not that good at controlling the actual speed of a motor. This method primarily controls the amount of torque that the motor puts out. If there is no load on the motor, then it will achieve top speed with a fairly low PWM value.

The second method where the motor is rapidly driven in opposite directions turns out to be a pretty good way of controlling a motor's speed. The speed versus PWM value ends up being pretty linear. There are certain situations where this method of driving an H-bridge fits in nicely with the type of math that you are using on your microcontroller.

The third method also produces a fairly linear speed versus PWM, but requires that you manually change the direction of the motor. This method gives you double the number of distinct speeds that you can command your motor to go, but — in reality — you are unlikely to notice much of a difference.

One question that arises when working with PWM is how fast should you do your PWM. The simple answer is that it depends on your application. You can successfully do PWM at rates of 1,000 Hz or lower, but you may find that the constant whine caused by the PWM quickly becomes annoying. On the other hand, you don't want to do your PWM too fast because the transistors or FETs used in H-bridges are not digital devices. They do not transition from fully off to fully on instantly. There is some amount of time during switching where they are not quite off and not quite on. During this time, a larger than normal amount of voltage will be dropped through these devices, causing them to dissipate more wattage as heat.

For the L293D H-bridge, it takes an average of 600 nanoseconds to transition from fully on to fully off and then fully on again. If you did your PWM at a rate of 1,666,666 Hz, you would be forcing the H-bridge to be in transition 100% of the time and would cause it to burn up almost immediately even with a small load attached to it. Even at much lower rates, the transition times can still cause the part to heat up significantly.

A general rule of thumb for setting the PWM rate for a motor is to put the frequency just high enough that the sound coming out of the motor is not loud enough to be

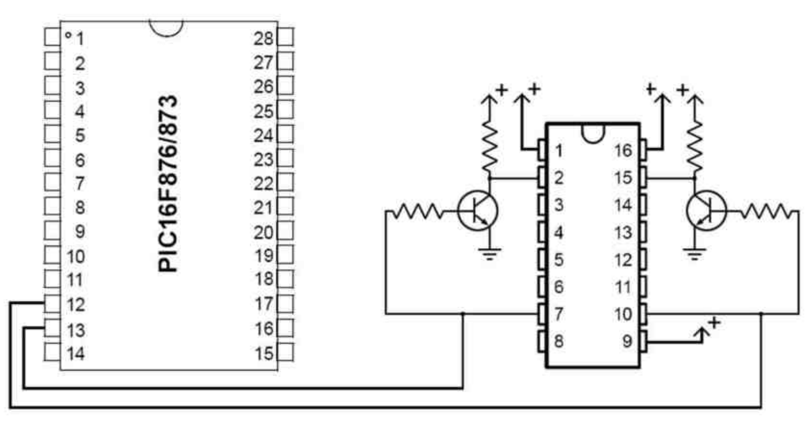


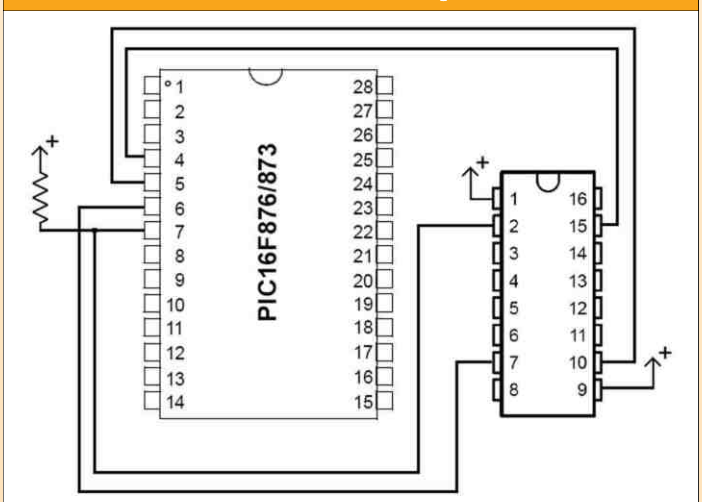
Figure 8. Controlling a motor using Locked Anti-Phase PWM.

annoying. The volume of the sound will decrease as you raise the PWM frequency. There are other things to consider, but — for most hobby applications — this is enough.

This is not quite good enough for the locked anti-phase strategy, though. Since this strategy is constantly sending power through the motor, it is always consuming power. Motors are essentially coils. When you power a coil, it takes a certain amount of time for the magnetic field to build up and then collapse. If you set your PWM rate too low, then the field will have enough time to fully collapse as you change directions. This will cause your power consumption to skyrocket. By setting your PWM rate higher, you will see a drop in the amount of power consumed by the motor when it is being driven with a 50% duty cycle PWM wave. The ideal frequency where the least amount of current is drawn may be well above the range of frequencies that a person can hear if your motor has low inductance.

This article has talked a lot about how to drive motors, but maybe some time should be spent on where you can get your hands on motors to drive in the first place. Certainly, the easiest way to find motors to get started with is from a toy.

Figure 9. Controlling a motor so that it is either driven or is braking.



TECH TIDBIT

www.ccsinfo.com
Sells the C compiler for PIC processors used in this column

www.microchip.com
Manufacturer of the PIC microcontroller

www.mouser.com
Source for electronic parts

www.solarbotics.com
Sells motors/gearbox combinations and other useful robot parts.

Remote controlled toys tend to make good robot bases, since they already have space to put batteries and have a complete drivetrain ready to use.

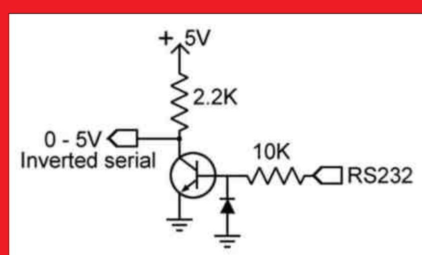
If you are the more adventurous sort (good for you!), then you might prefer to buy your own motors and gearboxes so that you build your own robot parts the way you want them to be. **Solarbotics.com** sells some really nice motor/gearbox combinations for prices that are well within a hobbyist's budget.

If you really want to fully engineer things and get your robots to peak performance, take a look at **maxon motorusa.com** where you can buy pretty much any size DC motor that runs at whatever voltage you want and can be connected to many different gearboxes with other things such as rotary encoders or tachometers. Be prepared for sticker shock when you ask for prices, though. A motor/gearbox combination from Maxon will set you back anywhere from $80.00 to $200.00 and there is a $250.00 minimum for orders. Even still, Maxon makes some really excellent motors and is definitely worth a look if you want to take your robot to the next level.

Hopefully, this month's column has opened your eyes to how you can get started using DC motors in your robots. Controlling DC motors using PWM is an easy thing to do with most microcontrollers and can open the doors to creating more exciting robots. **SV**

TECH TIDBIT

Would you like to be able to communicate with your PIC using your computer's serial port? Here is a handy little circuit that will take a RS232 signal and invert it while converting it to a 0-5 volt signal. If the microcontroller that you use doesn't need the inversion, switch the position of the transistor and 2.2K resistor.



Creating a Platform for AUTONOMOUS NAVIGATION on Ground Vehicles

by Jorgen Pedersen

In the summer of 2001, a need was evolving for a standard Unmanned Ground Vehicle (UGV) platform that research organizations could use to push the envelope of autonomous navigation. Thus, re^2, Inc. (which stands for Robotics Engineering Excellence), was born. re^2 was subcontracted by Carnegie-Mellon University's National Robotics Engineering Consortium (NREC) to build two semi-automated, all-terrain vehicles for the DARPA PerceptOR (Perception for Off-Road Mobility) Program. re^2 also provided a wireless pendant system to control the vehicles and an Ethernet interface to allow higher level control from Carnegie-Mellon's autonomous navigation system. This program pioneered new navigation and perception algorithms, producing the state-of-the-art in off-road autonomous navigation technologies. The program was successfully completed in May of 2004.

In July of 2004, re^2 licensed the robotic controller technology developed at Carnegie-Mellon's NREC for the PerceptOR program. The robotic controller technology encompasses both hardware and software to control the mobility functions of a UGV. Mobility functions include throttle control, steering, braking, and gear shifting for remote control or autonomous navigation.

re^2 is utilizing this technology in its own commercial UGV robotic platform. This Standard Heavy-duty Robotic Platform (SHERPA) enables researchers to focus on the technologies which are most important to their application without having to reinvent the UGV wheel. For example, one company may want to focus on testing cutting edge autonomous navigation software that will, someday, autonomously bring supplies to soldiers in the field. Another company may want to put sophisticated sensors on the SHERPA to help detect intruders for security or border control applications. Regardless of the application, the newly emerging ground robotics industry can immediately benefit from an off-the-shelf platform such as SHERPA. The base SHERPA vehicle contains all of the features and functions needed to test most advanced technologies. However, if additional features are needed, the SHERPA can be modified. Additional components are also available, such as a complete development station, an electric start generator, a retractable sensor mast, suspension deflection potentiometers, and a tactile sensor bumper.

The SHERPA utilizes an all-terrain vehicle (ATV) chassis, suspension, and engine. The additional support structure and roll cage are built from chromoly steel, which is stronger and lighter than mild carbon steel. This infrastructure supports all the electronic actuators required to control the UGV both remotely and autonomously. There are four degrees of freedom that are actuated electrically: steering, brakes, throttle, and gear shift.

The steering actuator experiences the largest power draw and can draw peak loads of nearly 1,000 W under severe conditions. Such conditions are mainly found in off-road driving. For example, a wheel may become stuck in mud. The forces required to steer out of such conditions are large. In some situations, the power output of the actuator may not be large enough to overcome the resistance (e.g., up against a rock). This fact dictates the selection of a work-horse actuator that is able to absorb the lost energy. Selecting an undersized actuator for such a situation would result in burning up the electric motor in the actuator and rendering it useless. The large actuator employed increases the reliability of the steering system.

The steering actuator is a linear actuator that can push or pull on a lever protruding from the steering column. A second lever is attached to the other side of the steering column, which a static arm works against. This second arm is mechanically connected to the linear actuator via a mechanical mixer. This mixing mechanism causes one lever to be pulled on while the other is pushed against, providing pure torque on the steering column, absent of side loads. Side loads would otherwise prematurely fatigue the steering system

The SHERPA fully-loaded with perception sensors as it existed under the DARPA FCS PerceptOR Program.

Brakes are automatically modulated as the SHERPA descends hills to maintain desired speed.

and cause it to fail. This push-pull electro-mechanical steering system was inspired by the servo linkages found on model helicopters and increases reliability for long term operation.

The steering control algorithm closes the control loop by using a rotational potentiometer on the steering column. A capacitor on the wiper signal of the potentiometer provides smooth operation of the actuator. In the absence of the wiper capacitor, the signal would be too noisy and would present the commonly found "hunting" actuator problem. Real world solutions like this make the difference between a good and an excellent product.

The drum brakes are controlled by a linear actuator that pulls on a cable. The brake actuator's position is based on the force feedback read from a load cell that is in-line with the brake cable. The control algorithm uses the load cell feedback to close the loop on the linear actuator.

The SHERPA engine is gas powered with a cable that controls the gas flow into the carburetor. A small linear actuator pulls on this cable. As more gas is supplied, the vehicle applies more power to the wheels and will drive the vehicle faster. However, just like a car, the gas output is not directly proportional to the speed. For example, as you drive your car up a hill, you must give the car more gas. To maintain a certain speed, the throttle (and brake) must be actively modulated by control algorithms. In order to do this, the control algorithms require speed feedback.

To get accurate speed feedback on the SHERPA, we embed an electric encoder into the engine. Encoders not only provide speed feedback, but also provide direction information (i.e., forward or reverse). Directional feedback is very important for gasoline-powered engines. For example, suppose that the vehicle is resting on and is pointed forward up a very steep hill. The vehicle disengages the brakes while simultaneously pulling on the throttle cable. Depending on the reaction time of the throttle actuator, the vehicle may begin rolling back down the hill before the throttle has enough power to propel the vehicle forward. Without direction feedback, the control algorithms will detect that the vehicle is already moving fast enough and release the throttle cable, but the vehicle would be traveling in the wrong direction! An encoder provides both the speed and direction information needed to overcome situations such as these.

On the SHERPA, located inside the transmission, the

ABOUT re², INC.

re², Inc., located in Pittsburgh, PA, is a Carnegie-Mellon spin-off company specializing in mobile defense robotics with an emphasis on unmanned ground vehicles (UGVs) and unmanned air vehicles (UAVs). re² has partnered with universities and industry leaders, such as Carnegie-Mellon and Exponent, Inc., to develop and support robotic technologies. As a defense subcontractor, re² has contributed to the development of mobile robotic technologies for the Defense Advanced Research Projects Agency (DARPA), the Army's Rapid Equipping Force (REF), the Office of Naval Research (ONR), and the Marine Corps. For more information, visit **www.resquared.com** or call (412) 681-6382.

encoder counts gear teeth. As the teeth pass by, the number of "ticks" read by the encoder is divided by the sample time. This result — when multiplied by the conversion factor between ticks and distance traveled (obtained through calibration routines) — provides the speed of the vehicle. To get the direction, two sensors are placed 90° out of phase from one another. This causes a pattern of 1s and 0s to be read. More specifically, a pattern of 10, 01, 00, 11 will repeat if moving in one direction and a pattern of 11, 00, 01, 10 will repeat if moving in the other direction. This pattern is called quadrature output. Finally — as an added benefit — by using two counters to create a quadrature encoder, four times the resolution is experienced in the speed calculation.

The SHERPA has been rigorously tested and enhanced at military installations across the nation over the past two years, making it one of the most reliable UGVs available today.

With a quadrature encoder providing the speed feedback, the control algorithms can servo the throttle and brake actuators to achieve the desired speed, regardless of terrain fluctuations. The control system employs hardened control algorithms, such as PID. PID stands for Proportional Integral Derivative. To better understand the PID algorithm, consider the following example. Suppose the vehicle is traveling forward up a hill. As the vehicle experiences the steepness of the hill, the Proportional term would increase the gas by an amount proportional to the error of the desired and actual speed. This increase should maintain the speed of the vehicle as it travels up the hill.

However, if the hill is too steep or if the vehicle drives up against a log, the Proportional term may not be enough to power the vehicle at the desired speed. To get the extra boost of power required, the Integral term would gradually increase the throttle until the desired speed is met or the vehicle is at maximum power. The Proportional and Integral terms may cause unstable behavior if not tuned properly. The Derivative term helps to tune the system and keep it from becoming unstable. Using the PID algorithm, in general, the throttle is automatically modulated in uphill situations and the brake is automatically modulated in downhill situations.

Gear shifting is controlled by a linear actuator through a series of mechanical linkages. A linear potentiometer provides the feedback required by the control algorithms to close the loop on the gear shifting position. All algorithms run on a Pentium-class embedded processor running QNX, a Real Time Operating System (RTOS). The RTOS is stored on a solid-state, compact FLASH module, which mitigates vibration and shock effects on the processor. All vehicle electronics interface to the embedded processor through an opto-isolated I/O rack.

A wireless pendant communicates over an RF link to the vehicle, up to 500 meters away. The pendant is equipped with joysticks and switches to control all aspects of the vehicle. Additionally, an Ethernet interface is provided to allow autonomous navigation systems to control the vehicle onboard.

The SHERPA platform has undergone extensive field testing over a three-year period in a variety of terrain and weather conditions. For vehicle specifications, visit **www.resquared.com/SHERPA.html** SV

ABOUT THE AUTHOR

Jorgen Pedersen, CEO, founded Robotics Engineering Excellence in July of 2001. He has been involved in robotics for over 10 years and holds two patents related to robotics.

GEAR MOTORS

SUPPLIER	Product	Model or Motor Size	Gear Reduction	RPM	Voltage	No Load Current
Astroflight www.astroflight.com	—	915P	19:1	1,014	6	5.0 a
	—	940P	15:1	1,080	24	3.0 a
Lynxmotion www.lynxmotion.com	—	COP-02	60:1	210	6	90 ma
	—	GHM-01	30:1	200	12	90 ma
	—	GHM-02	50:1	120	12	90 ma
	—	GHM-03	30:1	291	7.2	200 ma
	—	GHM-12	30:1	235	12	145 ma
	—	GHM-13	50:1	141	12	146 ma
	—	PGHM-02	27:1	222	12	50 ma
	—	PGHM-03	51:1	117	12	50 ma
	—	PGHM-07	19:1	210	12	75 ma
	—	PGHM-09	51:1	78	12	75 ma
	—	PGHM-13	19:1	263	12	120 ma
	—	PGHM-15	51:1	98	12	120 ma
NPC Robotics www.npcrobotics.com	—	NPC-41250	34:1	93	12	4.0 a
	—	NPC-R81	15.46:1	235	24	4.4 a
	—	NPC-T64	20:1	230	24	8.6 a
Solarbotics www.solarbotics.com	—	GM2	224:1	38	5	52 ma
	—	GM3	224:1	38	5	52 ma
	—	GM8	143:1	70	5	58 ma
	—	GM9	143:1	70	5	58 ma
	—	GM11	75.7:1	246	5	120 ma
	—	GM15	25.1:1	1,200	3	100 ma
Tamiya www.tamiyausa.com	Twin Motor Gearbox	130	58:1 or 203:1	189 to 55	3	160 ma
	Planetary Gearbox Set	260	16:1 or 400:1	631 to 25	3	170 ma
	Six Speed Gearbox HE	260	11.6:1 or 1,300:1	870 to 7.8	3	170 ma
	High Power Gearbox HE	260	41.7:1 or 64.8:1	250 to 160	3	170 ma

MATRIX

by Pete Miles

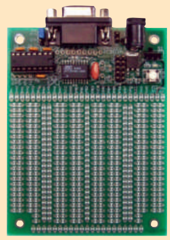
Upcoming topics include radio data links, and SBCs. If you're a manufacturer of one of these items, please send your product information to: **BrainMatrix@servomagazine.com** Disclaimer: Pete Miles and the publishers strive to present the most accurate data possible in this comparison chart. Neither is responsible for errors or omissions. In the spirit of this information reference, we encourage readers to check with manufacturers for the latest product specs before proceeding with a design. In addition, readers should not interpret the printing order as any form of preference; products may be listed randomly or alphabetically by either company or product name.

Stall Torque	Stall Current	Output Shaft Orientation	Shaft Diameter	Dimensions	Weight	List Price
800 oz-in	100 a	In-Line	4 mm	1.3" dia x 3.5"	9.5 oz	$250.00
3000 oz-in	100 a	In-Line	12 mm	1.7" dia x 5"	25 oz	$360.00
4.86 oz-in	1,300 ma	Offset	3 mm	0.63" dia x 1.57"	0.86 oz	$21.95
63.9 oz-in	1,500 ma	Offset	6 mm	1.45" dia x 1.92"	5.36 oz	$21.95
213.5 oz-in	3,800 ma	Offset	6 mm	1.45" dia x 2.33"	7.15 oz	$29.95
123.2 oz-in	1,500 ma	Offset	6 mm	1.45" dia x 1.92"	5.36 oz	$21.95
302.8 oz-in	1,200 ma	In-Line	6 mm	1.42" dia x 3.15"	11.68 oz	$24.00
138.9 oz-in	3,800 ma	Offset	6 mm	1.45" dia x 2.33"	7.15 oz	$29.95
42.2 oz-in	750 ma	In-Line	4 mm	0.94" dia x 2.17"	2.72 oz	$15.25
79.7 oz-in	750 ma	In-Line	4 mm	0.94" dia x 2.36"	3.04 oz	$17.50
51.5 oz-in	1,000 ma	In-Line	6 mm	1.10" dia x 2.76"	4.16 oz	$19.53
138.1 oz-in	1,000 ma	In-Line	6 mm	1.10" dia x 2.99"	4.48 oz	$22.00
112.8 oz-in	1,200 ma	In-Line	6 mm	1.42" dia x 2.83"	10.04 oz	$21.30
302.8 oz-in	1,200 ma	In-Line	6 mm	1.42" dia x 3.15"	11.68 oz	$24.00
260 in-lb	56 a	Right Angle	0.5 in	3.64" x 5.83" x 8.9"	7.5 lb	$155.00
896 in-lb	105 a	Right Angle	0.75 in	4.7" x 5.0" x 12.3"	15.0 lb	$285.00
825 in-lb	110 a	In-Line	1.469 in	5.64" x 5.47" x 10.12"	13.0 lb	$286.00
50 oz-in	600 ma	Offset	7 mm	2.17" x 1.89" x 0.91"	1.31 oz	$7.25
50 oz-in	600 ma	Right Angle	7 mm	2.76" x 0.89" x 1.46"	1.31 oz	$7.25
43 oz-in	670 ma	Offset	7 mm	2.17" x 1.89" x 0.91"	1.13 oz	$7.00
43 oz-in	670 ma	Right Angle	7 mm	2.78" x 1.06" x 0.91"	1.13 oz	$7.00
11 oz-in	580 ma	In-Line	3 mm	0.39" x 0.47" x 1.14"	0.29 oz	$23.00
0.28 oz-in	215 ma	In-Line	1.5 mm	0.24" dia x 0.79"	0.04 oz	$19.00
12.8 - 41.7 oz-in	1.1 a	Right Angle	3 mm	1.75" x 0.9" x 2.94"	2.46 oz	$11.50
3.3 - 83.3 oz-in	1.0 a	In-Line	4 mm	1.35" x 1.4" x 2.75"	2.46 oz	$18.00
2.2 - 208 oz-in	1.0 a	Right Angle	4 mm	1.72" x 1.06" x 2.7"	2.46 oz	$16.50
9.3 - 13.9 oz-in	1.0 a	Right Angle	4 mm	2.36" x 1.10" x 2.7"	2.12 oz	$12.00

New Products

ACCESSORIES

Prototyping PC Board for Atmel ATTINY26



Pololu introduces the first of its new line of partially assembled prototyping printed circuit boards for Atmel's AVR line of microcontrollers. The first board supports the 20-pin ATTINY26, which features 128 bytes of SRAM and 2 Kb of Flash program memory. The circuit board includes all connections and footprints for an LP2950 voltage regulator, resonator or crystal, reset circuit, power jack and switch, RS-232 level converter with DB9 connector, and in-circuit programming header. All of the power and I/O lines are brought out to the edge of the prototyping area for easy access.

To save space and reduce the time necessary to get a project running, the main microcontroller and supporting circuitry are assembled with surface-mount packages. The optional RS-232 circuitry, reset push-button switch, resonator or crystal, power jack and switch, and in-circuit programming header can all be populated with through-hole components. The bare PC board without the surface-mount components assembled is also available.

The prototyping grid has pads connected in pairs and triplets for easy circuit building in configurations similar to those used on a solderless breadboard. Five longer bus lines simplify distribution of nets with many connections, such as power and ground lines. All of the prototyping grid connections are routed on the bottom layer of the board so that they can easily be cut if necessary and all of the connections are clearly indicated on the white silkscreen on the top side. The grid can hold up to two 40-pin DIP packages and two 20-pin DIP packages or up to eight 20-pin DIP packages.

The PC board measures 3" x 4" and also features plated-through holes and solder masks on both sides. The unit price is $20.00 for the partially assembled board (part #0389), $12.00 for a bare board (part #0388).

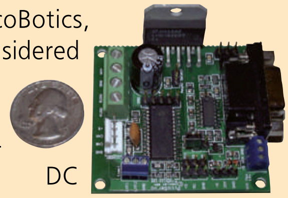
For further information, please contact:

Pololu Corp.
6000 S. Eastern Ave., Ste. 5-E
Las Vegas, NV 89119
Tel: **877•7•POLOLU** or **702•262•6648**
Fax: **702•262•6894**
Email: **www@pololu.com**
Website: **www.pololu.com**

Circle #125 on the Reader Service Card.

CONTROLLERS & PROCESSORS

DC Servo Controller



The new Pico*Motion*™ from PicoBotics, Inc., is considered one ofthe smallest and most feature-rich DC brushed motor controller on the market. With 11 modes of operation, the end user is sure to find a mode for any application. Quadrature

encoders of up to 2,048 CPR are supported. Some of the features include:1x, 2x, 4x encoder decoding, 12 trapezoidal profiles, 10 PID settings, current monitoring and reporting, analog control, R/C control, and RS232 and TTL serial control with any combination of the above. With data logging and upgradeable firmware, this small board (2" x 2") is the biggest commotion in motion control. Pico*Motion*™ includes Pico*Talk*™ setup and servo tuning software for Windows®.

Operating range is from 12 to 50 volts at currents of up to 3 A continuous (6 A surge). Pico*Motion*™ costs $95.00.

For further information, please contact:

PicoBotics, Inc.	Website: **www.picobotics.com**

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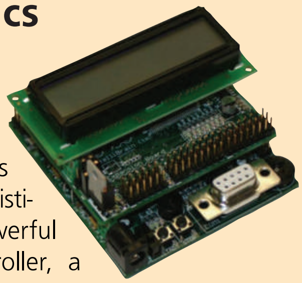
IntelliBrain Robotics Controller



RidgeSoft has recently released the IntelliBrain™ robotics controller, which makes it easier than ever to build sophisticated, intelligent robots. The powerful Atmel® ATmega128 microcontroller, a modern, object-oriented programming language, Java™, a rich robotics class library, up to 48 sensor and effector ports, and a flexible human interface give the IntelliBrain robotics controller what it takes to be an intelligent robot's brain. The IntelliBrain controller easily mounts on a robot chassis constructed from LEGO® bricks, the Mark III mini sumo chassis, or just about any other robot chassis.

Each of the IntelliBrain controller's analog, digital, serial (RS232), I^2C, and servo ports provides a header with power, ground, and signal pin(s), making it easy to interface to sensors and effectors.

The RoboJDE™ Java-enabled robotics software development environment (included with IntelliBrain) is an easy-to-use, integrated development environment that includes a Java class library with support for the CMUcam, Sharp IR range finders, Devantech sonar range finders, compass, speech synthesizer, motor controllers, WheelWatcher™ shaft encoders, Fairchild infrared photo-reflectors (line sensors), hobby servos, DC motors, universal infrared remote controls, and more. The numerous classes in the library provide a great foundation that simplifies robot intelligence programming. Building upon the class library to support additional sensors, effectors, and control logic is a snap.

A 16 x 2 liquid crystal display, two push buttons, a

thumbwheel, a buzzer, LEDs, and an infrared remote control receiver provide a flexible, programmable human interface to the IntelliBrain controller.

The IntelliBrain controller consists of a main board and an optional expansion board.

The IntelliBrain main board features are:

- Atmel ATmega128 microcontroller running at 14.7 MHz
- 132K RAM
- 128K Flash memory
- 4K bytes EEPROM
- 16 x 2 LCD display
- START/STOP buttons
- Thumbwheel
- Buzzer
- Two program controlled LEDs
- RS232 host port, up to 115.2K
- Secondary RS232 port, up to 115.2K — includes power pin for the CMUcam
- Seven analog/digital input ports
- 10 digital input or output ports
- I^2C bus with three sensor connectors that include power and ground
- Two servo ports
- One 38 kHz modulated IR receiver
- Expansion board support
- Easy to mount on LEGO constructed chassis, Mark III mini-sumo chassis, many commercially available chassis, or a custom chassis
- Java programmable using RoboJDE

The IntelliBrain expansion board adds the following features:

- Four PWM DC motor ports
- Seven analog/digital input ports
- Eight digital input or output ports
- Six servo ports
- 64K bytes EEPROM
- Eight program controlled LEDs
- One program controlled 38 kHz modulated LED plus support for two others via digital I/O ports
- Support for an optional secondary battery up to 15 V
- Optional servo power regulation

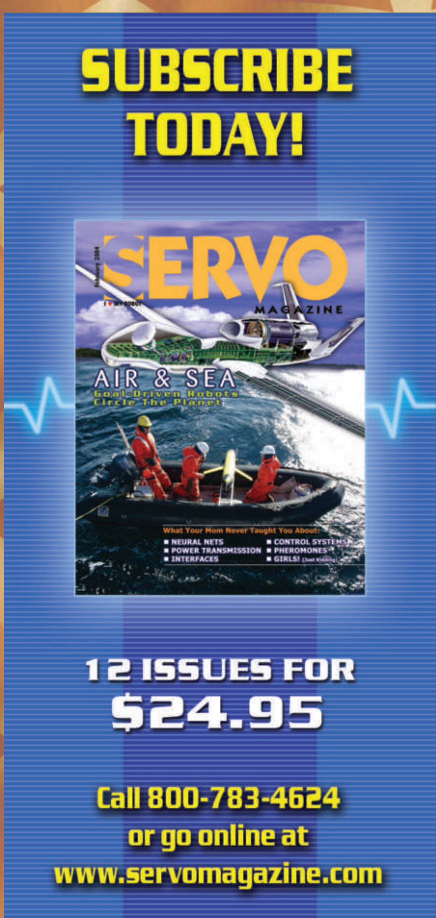
For further information, please contact:

RidgeSoft, LLC
P.O. Box 482
Pleasanton, CA 94566
Email: **info@ridgesoft.com**
Website: **www.ridgesoft.com**

Circle #136 on the Reader Service Card.

(continued on Page 89)

Robotics Showcase



EVENTS CALENDAR

Send updates, new listings, corrections, complaints, and suggestions to: **steve@ncc.com** or FAX **972-404-0269**

Look for a number of interesting robot events this month. The November ChiBots contest will be held in a new venue and includes a new maze-solving event. The finals for both the Texas BEST and South's BEST will also be held in November. The Texas BEST final is a worth seeing for its sheer size alone. There are sometimes teams from as many as 60 schools competing. November also includes events in Spain, Japan, and Canada. So, no matter where you live, there's probably a robot competition worth seeing (or participating in).

— R. Steven Rainwater

For last minute updates and changes, you can always find the most recent version of the complete Robot Competition FAQ at Robots.net: **http://robots.net/rcfaq.html**

November

6 **CIRC Autonomous Robot Sumo Competition**
Peoria, IL
In addition to sumo, this year's event includes some R/C combat events.
www.circ.mtco.com/competitions/2004/menu.htm

10 **AESS National Robotics Contest**
Barcelona, Spain
Based on the photos available at the website, this is a student contest for line followers and sumo robots.
http://aess.upc.es/concursrobot/

12-13 **Texas BEST Regional Competition**
Moody Coliseum, SMU, Dallas, TX
Students and corporate sponsors build robots from standardized kits and compete in a challenge that changes each year.
www.texasbest.org/

13-14 **Eastern Canadian Robot Games**
Ontario Science Centre, Ontario, Canada
Includes BEAM events, including autonomous sumo and a fire fighting competition.
www.robotgames.ca/

14 **ChiBots Robotics Contest**
SciTech Museum in Aurora, IL
A new maze solving event has been added to the usual line-up of sumo, line following, and solar-roller events. Also, note that the contest is being held at a different location than previous events.
www.chibots.org/

19-21 **All Japan MicroMouse Contest**
Tokyo, Japan
The latest in a long-running series of micromouse contests includes some of the fastest micromouse robots around.
www.bekkoame.ne.jp/~ntf/mouse/taikai/taikai.html

19-20 **South's BEST Competition**
Beard-Eaves Memorial Coliseum, Auburn University, Auburn, AL
Students and corporate sponsors build robots from standardized kits and compete in a challenge that changes each year.
www.southsbest.org/

22 **Texas BEST Competition**
Reed Arena, Texas A & M University
College Station, TX
This is the big one, where the winners from the regionals compete.
www.texasbest.org/

26-27 **War-Bots Xtreme**
Saskatoon Saskatchewan, Canada
Robots (R/C vehicles) attempt to destroy each other to win a whopping $10,000.00 in prize money.
www.warbotsxtreme.com/

December

6 **Hawaii Underwater Robot Challenge**
University of Hawaii, Oahu, HI
Regional for the MATE ROV competition.
www.phys.hawaii.edu/~aapt/calendar/events2003-04.html

11 **Boonshoft Museum LEGO Mindstorms Robotics Competition**
Boonshoft Museum, Dayton, OH
This year's robotics competition will be a FIRST LEGO League event. The usual FIRST rules apply.
www.boonshoftmuseum.org/special_events.php3

11 **LEGO MY EGG-O Robotic Egg Hunt**
Great Lakes Science Center, Cleveland, OH
A robot egg hunt for students of the Case Western Reserve University Autonomous LEGO Robotics class.
www.eecs.cwru.edu/courses/lego375/egghunt.html

17-18 **RoboPraxis**
Cherry Hill, NJ
For this event, South Jersey Robotics Group has some very interesting events planned, including a robot dancing contest, a collision avoidance event, and a special contest just for RoboSapiens.
www.sjrobotics.org/

January 2005

24 **Citrus Robotics Robot Combat**
Inverness, FL
Radio controlled vehicles destroy each other in Florida.
www.citrusrobotics.com/

28-30 **Techfest 2005**
IIT, Mumbai, India
A nationwide science and technology festival for Indian students. There are several robot contests, including Yantriki and Survivor.
www.techfest.org/

February 2005

4-6 **Robotix**
IIT Khargpur, West Bengal, India
Organized for students of ITT Khargpur, this contest includes events for both autonomous robots and radio controlled machines.
www.robotixiitkgp.com/

March 2005

6-10 **APEC Micromouse Contest**
Hilton Hotel, Austin, TX
This will be the 18th annual APEC micromouse event.
www.apec-conf.org/

11-12 **AMD Jerry Sanders Creative Design Contest**
University of Illinois at Urbana-Champaign, IL
The design problem is new and different each year. Check the website for the latest news.
http://dc.cen.uiuc.edu/

MENAGERIE

Send us a high-res picture of your robot with a few descriptive sentences and we'll make you famous. Well, mostly. menagerie@servomagazine.com

Stepmother!

Sue Carroll, Eastsound, WA

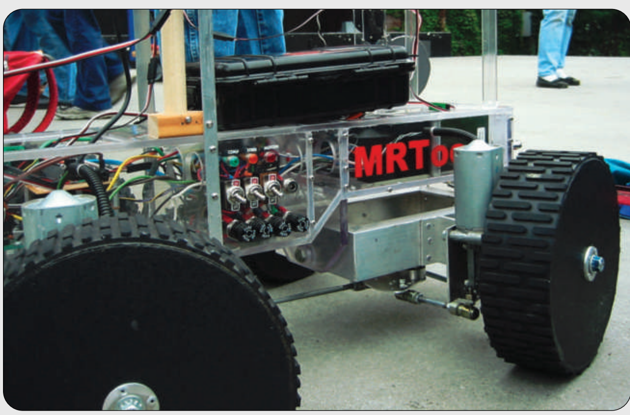
To give you a bit of background, the Southern California Robotics Society (what it was called before 1989, when its name was changed to the Robotics Society of Southern California) ordered 17 robots from the dying Androbot Corporation for about $125.00 each. We then ordered 17 more — all they had left — and that included gel cells, chargers, and a transmitter that worked with an Apple II. Just for the fun of it, I unpacked all of them — they were stored in my garage until everyone came by to stake their claims — and arranged them around the living room. I posed for this photo, reading a *Robotics Age Magazine* to them. I believe that our group bought more TOPOs than Androbot sold altogether to anyone else!

Arachnibot P1

Christopher Wagers, Lake Oswego, OR

The Arachnibot is a walking platform that can climb obstacles more than twice its height. It is made from machined polycarbonate and is designed for the harshest environments. Every component and function has been engineered for strength and expandability. It can sense objects and respond to them as it moves, using a closed-loop locomotion system. This is my research tool, whether I am working in a search and rescue mode or designing a robust platform for Mars!

info@videoptions.com



MRToo

Daryl Sandberg and Larry Geib, Beaverton, OR

MRToo won the SRS/*SERVO Magazine* Robo-Magellan competition, held at Robothon on September 25th, 2004.

The robot has four-wheel drive and four-wheel steering. Four windshield washer motors are used as drive motors and a power window motor is used for steering. Four 12 V lead acid batteries provide the power for the motors and electronics, giving the robot about a 1/2 mile range. Daryl hand-built the wheels from plastic sheet and floor matting. It has a BASIC Stamp 2 microcontroller for brains and reads a Garmin GEKO 201 GPS and a Devantech CMPS-01 compass for navigation. The robot follows a route directed by the GEKO's route mapping function, pausing when the GPS determines that a waypoint is near to look for cones. Oh, the name means "Moon Rover, Too!"

SandbergDJ@aol.com


PROGRAM
100 LBS
sponsored by SERVO
TETSUJIN COMPETITION

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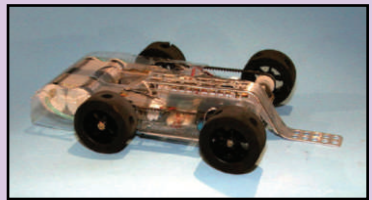
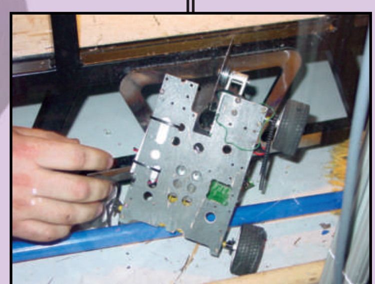
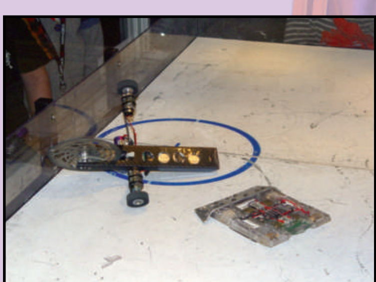
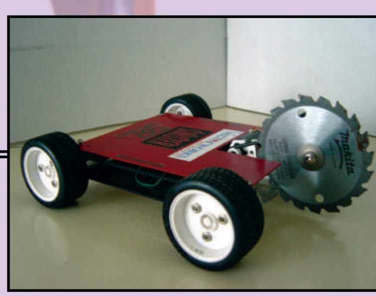
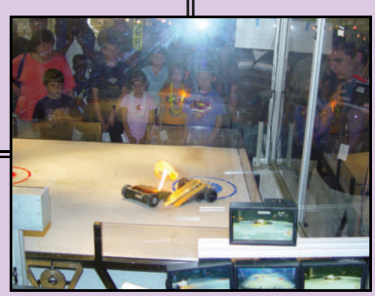


CHECK OUT THESE SOZBOTS ON PAGE T46









EVENT SCHEDULE

FRIDAY		SATURDAY	
11:30 - 12:30	Lift #1	11:30 - 12:30	Lift #3
3:00 - 4:00	Lift #2	3:00 - 4:00	Lift #4

Note that times are subject to change, so check the Tetsujin area for last minute updates!

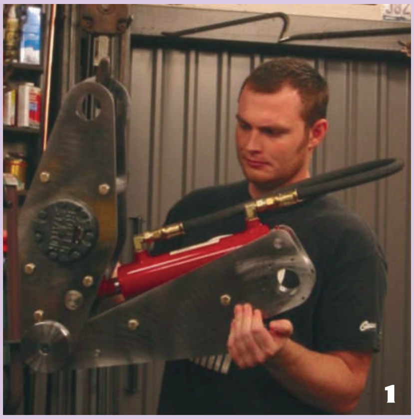
Wonder how those lift scores are calculated? They come from a four-term formula that was disclosed early on to the competitors. This allowed them to maximize any of the terms they wished to for their unique designs.

$$\text{Score} = \frac{\text{Lift Height (cm)} \cdot \text{Lifted Weight (kg)}}{\text{Lift time (sec)} \cdot \text{Total System Weight (kg)}}$$

So, a 300 kg suit (with operator) lifting 300 kg the full meter in 2.2 seconds earns a score of (100 • 300)/(2.2 • 300) = 45.45

Competitors had to decide if they would shoot for lifting a large amount of weight or lifting it quickly. As you can see, one team lifting 100 kg in one second does just as well as a team that lifts 200 kg in two seconds — but the first team doesn't need as heavy of an exosuit to lift 100 kg! Since this is a "strength augmentation" contest — not one of strength replacement — smart competitors have been doing their push-ups every day to give a hand to their mechanical systems.

THE ROAD TO TETSUJIN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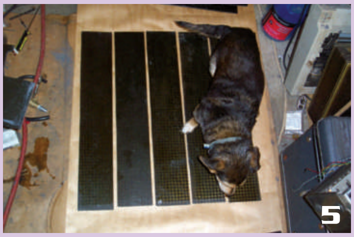
2


3


4

1. Jascha Little of *Mechanicus* examines a hydraulic leg joint. **2**. *Team Technotrousers'* wooden mock-up. **3**. Alex Sulkowski of *Xela* told everyone he could walk in his suit. This caused a great deal of worry! **4**. The softer side of Chuck Pitzer from *Team Raptor*. **5**. Billy Holcomb's mascot, *Chip,* helps apply "bonding pressure" while the carbon fiber sets up. **6**. Dan Rupert of *Technotrousers* performs an early lift in these frames from his video. **7**. The lead screw in the foot of the *Technotrousers*.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6


7

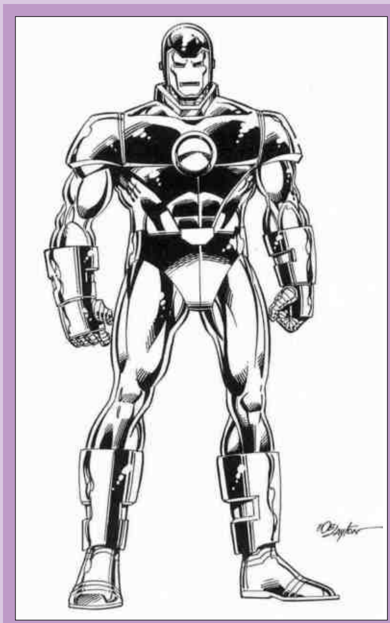
The Philosophy of Tetsujin

You see, this all started with a comic book. Back in 1987, I was studying physics at UC Irvine and — to help me relax — I enjoyed the art of Bob Layton in the Marvel title, *Iron Man.* If you're not a comic book fan, don't worry, I won't bore you, other than to say that this comic wasn't about magic, telekinetics, X-factors, or any of that junk. It was about a smart engineer, Tony Stark, who built a machine to augment his strength and perception. Of course, he was *inside* that machine, so it ultimately became an extension of his will to help people.

I always imagined that — through the mastery of electronics, mechanics, materials science, software, and biomechanics — other engineers could achieve the same feat, extending their physical abilities the way Stark did. There was no mystery, just a path of focused study and effort, backed by research funds.

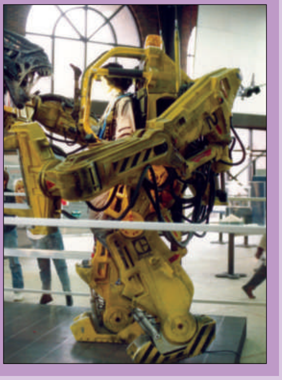
The cornerstones of this technology were actually laid by Ralph S. Mosher of General Electric in the 1950s. Mosher worked in the R&D lab on force feedback systems and hydromechanical servo valves, eventually culminating in the HardiMan Suit. (You've probably never seen it, so I've included a photo. I have no idea what the hard hat is for!)

Around that time, Robert A. Heinlein published his book, *Starship Troopers*, which featured an off-world, mobile infantry encased in hulking exosuits that let them hop about and carry huge weapons into battle. The sci-fi connection was further developed in the 1986 movie, *Aliens*, where Lt. Ripley employs a "walking forklift" in the final battle with the alien queen. Clearly, exosuits have been on people's minds for a while.



A fully realized exosuit, Iron Man. Image courtesy of Bob Layton.

Mosher's HardiMan suit, circa 1965.



The Cat Power Work Loader from the movie *Aliens*.

So, how does this all coalesce into the Tetsujin event at RoboNexus? In the same way that Pythagoras assigned tones to the planets and referred to the "music of the spheres," during their alignment, we're in the middle of a Mozart recital — as seen from a technological perspective. When I'm asked why we're holding this event, my answer is, "Why not? What in the world are we waiting for?"

When Larry and Robin Lemieux and I sat down to plan the vision for *SERVO Magazine*, we all wanted it to become the force for something valuable to society. We weren't content to just report on the emerging personal robotics industry; we wanted to help drive it. So, when I thought up the premise for Tetsujin in late 2003, I knew it was a winning idea. Here, we could get top electromechanical engineers to compete in a way that people could relate to, while motivating them to develop a technology that people would one day be thankful for.

Robots are the hot topic these days. They pop up on CNN as they rove over planetary surfaces, collect bacteria from the deepest trenches of the ocean, and provide recon info for police and military operations. Students memorize their names and functions right alongside the bones and muscles of the body. The age of robotics is now.

Are the initial competitors of Tetsujin fielding exosuits on par with the sci-fi movies? No, but then again, these are the *Monster Garage* builders that weld and design at night, not the researchers with seven figure development budgets and 36 month project timelines. I will point out that not a single university robotics department entered the competition this year and I know why: the tendency to overcomplicate. The challenge is simple and I hope that qualified engineers realize that a roll of newspaper works just as well as a CO_2 laser with Doppler tracking for swatting a fly.

Finally, the role of exosuits in society will increase and, in time, they'll become like microwave ovens — we'll wonder how we ever did without them. I predict that every fire station will have a limited form of exosuit on hand so that first responders can quickly reach trapped victims. The elderly will have increased mobility as lighter-duty versions return strength to their legs and hips. Heck, FedEx bought a plug in the film *I, Robot* so, maybe their drivers will be wearing exosuits in a few years!

Every project begins with a single idea and that idea is instantiated by putting a pen to paper. The idea that robotics will allow humans *be more human* is the arch that holds up the Tetsujin competition and it begins right here, as these weights are lifted before your eyes.

— Editor Dan Danknick

STEVE JUDD

Developer and Moderator of Tetsujin 2004 Rules

After 27 years as a software developer and architect in such diverse fields as operating systems, industrial and laboratory robotics, and manufacturing control, Steve Judd has turned his considerable trove of knowledge and experience to the robotics field. A founding member and officer of the Robot Fighting League (**www.botleague.com**) and a principal of COMBOTS, LLC — a company dedicated to producing robotic competitions — Steve has created some of the most well-known, feared, and admired entries in the combat robotics community.

His attitude toward the products of mechanical engineering — the bigger, the better — is a perfect fit for Tetsujin. His involvement with the event was a manifestation of that interest; when Dan Danknick first mentioned the exoskeleton competition, Steve immediately wanted to be involved. His goal is to have the initial challenge hard enough to be interesting, but possible for a wide range of competitors. When not reigning over the robotic multitudes, Steve's interests turn to baseball, photography, and giant squids (again, the bigger, the better!). Visit his website **www.architeuthis-dux.com** or Email him at sgjudd@verizon.net

DAN DANKNICK

Technical Editor of SERVO and Nuts & Volts

Dan Danknick is the architect of the Tetsujin 2004 event. As a long time fan of the comic book hero Iron Man, Dan has been intrigued by the good that strength augmentation suits could do for society for over 20 years. Residing in Southern CA, he is the Technical Editor of *SERVO* and *Nuts & Volts* — the culmination of a long history with the publishers. Dan holds the Tetsujin competitors in the highest regard for taking up his vision for this event and committing their time and energy to the promise that it holds. He can be reached at dan@servomagazine.com

ROY HELLEN

SOZBOTS Announcer

An icon in robot competitions, Roy Hellen is the SOZBOTS announcer. Wherever there is a cool event, Roy is sure to pop up — though normally wearing a suit of medieval armor (no joking!). A resident of California's Bay Area, Roy currently works as a Product Manager for GDR, a geographical information service. In his free time, he likes to ride fast motorcycles and do other cool things like throw boomerangs and tinker in his electronics lab. Roy can be reached at roy@botcast.com

JEFF KELLOUGH

Tetsujin Announcer

Jeff Kellough, the Tetsujin announcer, works as a manufacturing engineer at Celerity in Southern California. He has extensive knowledge of mechanical systems, materials selection, and electronic controls. Jeff thinks the coolest invention of all time is microwave pizza. He can be reached at jkellough@celerity.net

SERVO Magazine would also like to thank our event volunteers for their time and effort in making Tetsujin 2004 such a success! Way to go, Stephen Felk, Nora Judd, Chuck Micnacco, and the Woolley family — Bill, Deb, Bryce, and Evan!

BINARY BOT BOYZ

— HURST, TX —

Billy Holcombe, his son, Jonathan, and his wife, Karen form this team. With the contributions of various coworkers and the support of the family, Binary Bot Boyz has created a high strength carbon fiber and honeycomb suit (materials that aircraft rely upon for their high strength-to-weight ratios). This has created an exosuit that boasts of strength around 920,000 lbs per square inch. Using these materials wasn't easy, though; they present challenges far removed from conventional metal construction. The fabric is about .015" thick and must be layered to the thickness needed, then placed under vacuum, pressure, and heat to cure the resins impregnated into it. Two thicknesses of pre-cured material of .180" and .350" were available and were layered around the perimeter of the parts and compressive points, with the core areas filled with paper/epoxy or fiberglass/epoxy honeycomb.

XELA

— NEW CANAAN, CT —

Financial services consultant Alex Sulkowski is an army of one, constructing his suit solo. Nonetheless, he brings to Tetsujin what we believe to be the only exosuit capable of walking! This ambitious exoskeleton allows a normal paced walk (even a slow jog) in addition to augmenting the lifting of weights. This is accomplished through a design that utilizes the operator's strengths and the strengths of the suit while minimizing their respective weaknesses. Since the suit is very flexible — with little resistance in all of the operator's joints — the wearer can walk by providing the necessary coordinated motion. When lifting weights, many of the suit's joints reach the limit of their ranges of motion and bear the weight of the load. This eliminates the need for coordinated motion of multiple joints when lifting the load, while allowing fast lifting via pneumatic cylinders. Very short lifts of heavy loads are the result.

TEAM TECHNOTROUSERS

— SAN DIEGO, CA —

Dan Rupert and Donald Engh, both engineers by degree, break away from the norm to take a different approach with their exoskeleton design by using the KISS strategy to an extreme. Their suit is a purely mechanical system based around an Acme screw drive. There are no hydraulics or pneumatics. Anticipating next year's Tetsujin competition, the team is already hard at work with their next generation suit, which will have more degrees of freedom than the current build. Dan started his career in aerospace before shifting his focus to bring high school students into the fields of math, science, and pre-engineering. Don currently works with a sheet metal company, pioneering laser cutting techniques. Veterans of *BattleBots*, BotBall, and FIRST mentoring, this team's varied approach makes it worth keeping an eye on!

MECHANICUS

— AUSTIN, TX —

This father and son team of Scott and Jascha Little brings volumes of robotics experience to the competition. Having competed in many robotics events, Jascha looks forward to Tetsujin for the simple reason that the event does not involve another competitor trying to destroy the culmination of his labors. There are no spinners in Tetsujin! In addition, he has the opportunity to compete in the brainchild of Dan Danknick, whom Jascha cites as a key influence in robotics. When he started out in robotics, Jascha found Dan's builds to be a valuable resource; he sought to build robots that would stand up to and defeat Dan's creations. Leaving combat robotics to build an exoskeleton is a long-standing dream of Jascha's; a science fiction fan, he was always intrigued by the concept of augmented strength and motion. Now, he likes to think that, theoretically, his Tetsujin design could be used in a myriad of applications. Mechanicus claims that their suit will likely be the most overbuilt suit at the event — it will be the toughest and strongest suit, designed to complete the maximum lift weight. The team thanks the companies who have helped them in their efforts: White Hydraulics for the motors, Hydraforce for the hydraulic valves, and US Digital for the encoders. In addition, Accumulators, Inc., and Womack, Inc., provided the team with discounts.

THE WIDGETS

— SANFORD, FL —

As Tetsujin's only high school team, the Widgets acknowledge Tetsujin as a learning experience. They plan on making the competition an annual event to hone their skills. Their exoskeleton is the first major build they will have ever entered in a large competition. The event offered them a prime example of the skills they wished to learn and try out — particularly hydraulics and pneumatics — in addition to the non-technical skill of perseverance. The event itself provides a tall order for this team, as they must jet back to school to resume their demanding International Baccalaureate studies. Citing Mark Tilden's analog robotics as a key influence, along with his engineer parents, team leader Bryan Hood wants the spectators to come to see what a bunch of students can put together when they put their minds to it and try their hardest. He claims beginners' luck will help his team win the title of Tetsujin 2004.

TEAM RAPTOR

— EL SEGUNDO, CA —

Team Raptor, led by Chuck Pitzer, is an experienced set of builders with the resources and know-how to push the limits of exoskeleton development. This mechanical marvel's raw hydraulic muscle will max out the weight lifted in short order. High lift weight-to-skeleton weight ratios will be the focus of this design. A smooth operating motion will try to trim down lift times.

SOZBOTS — Sixteen Ounce Robots

Sozbots is teaming up with *SERVO Magazine* to help make the upcoming Tetsujin event a big hit at this year's RoboNexus in Santa Clara, CA.

Specializing in 16 oz combat robots called Antweights, Sozbots produces tournaments, in addition to designing and distributing robotic products. With their well-engineered portable arena, they have traveled around the West Coast, holding over 20 tournaments in the past three years.

Sozbots is a company formed by four film industry workers who are veterans of robot combat, including *BattleBots* and *Robot Wars*. In 2000, the founding members created the first speed controller for the Antweight class and held a small tournament. Interest grew and Sozbots was born.

Always trying to build a better mousetrap, Sozbots has continued to refine and improve the Soz speed controller, as well as produce high quality and innovative products for small robots — such as a universal chassis plate and custom motor mounts. Collecting products from around the globe and designing kits makes **Sozbot.com** your one stop robot store.

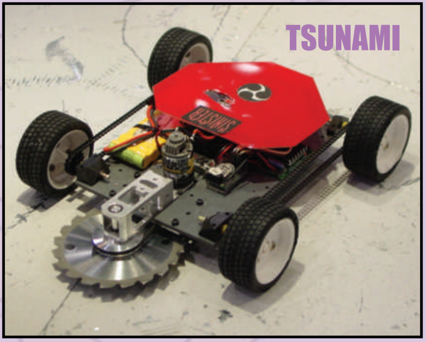
With the introduction of the KHR-1 Biped Walking Robot Kit, Sozbots is venturing into the world of the Robo-One competitions that are currently so popular in Japan. You can find more information about the kit at: **www.robo-one-usa.com**

If you are interested in kits for individuals, schools, or camps, please contact Sozbots at peter@sozbots.com They can help you create a custom kit and curriculum to suit your needs.

To find out more about building your own Sozbot or where and when competitions are being planned, check out: **www.sozbots.com**

MEET THE BOTS!


LB (1 POUND)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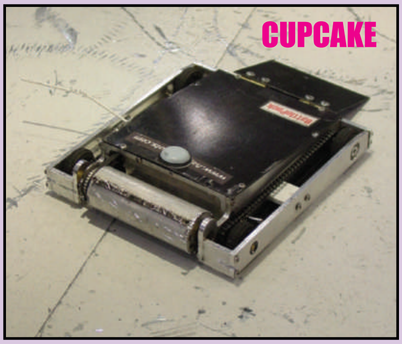
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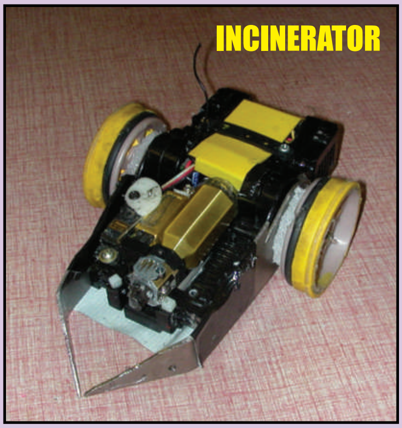
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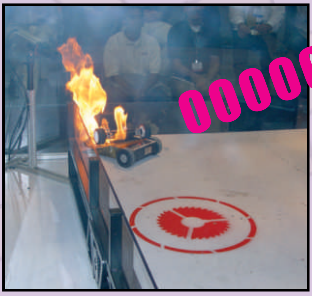

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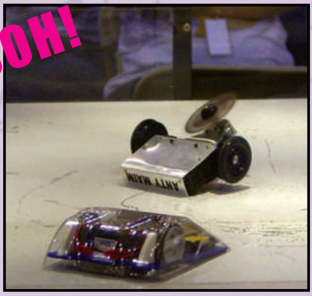

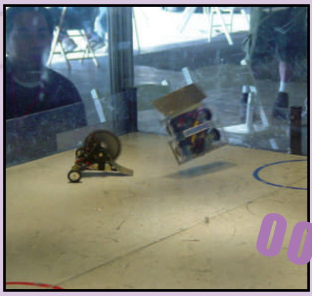

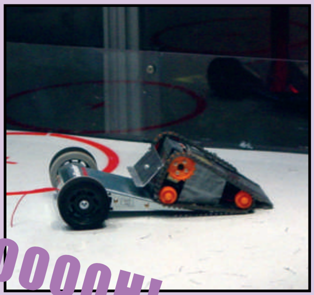

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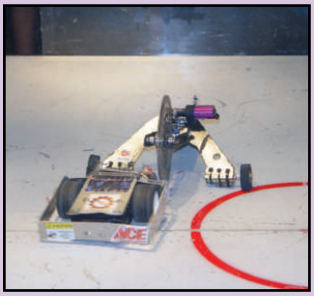

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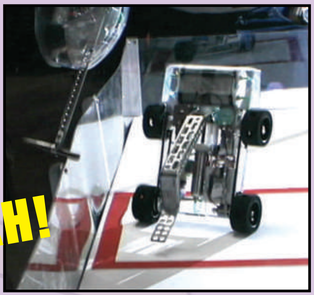

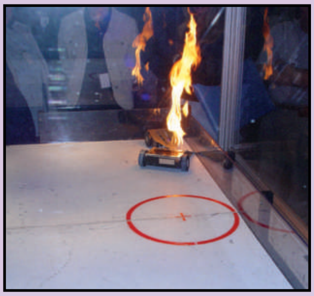

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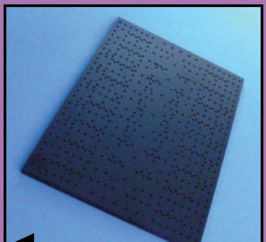

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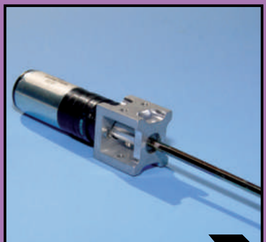

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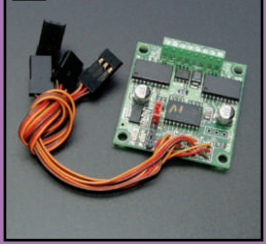

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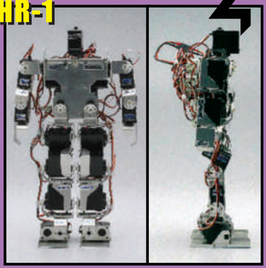

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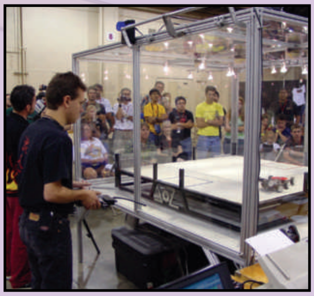

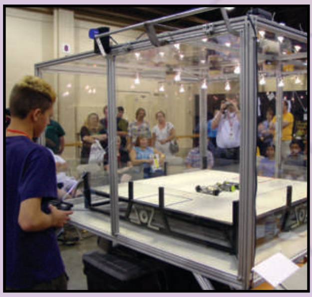

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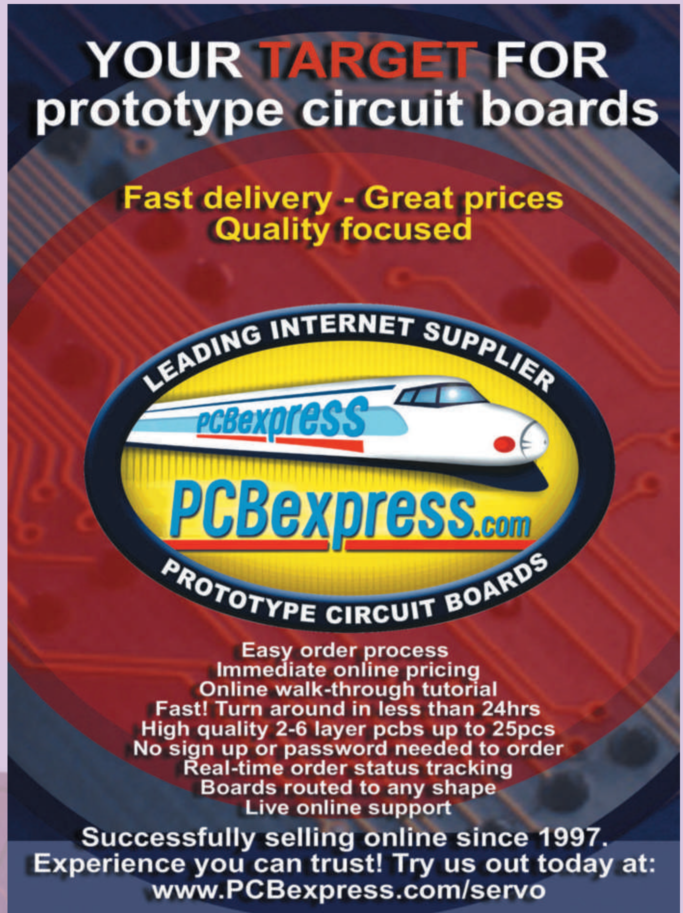

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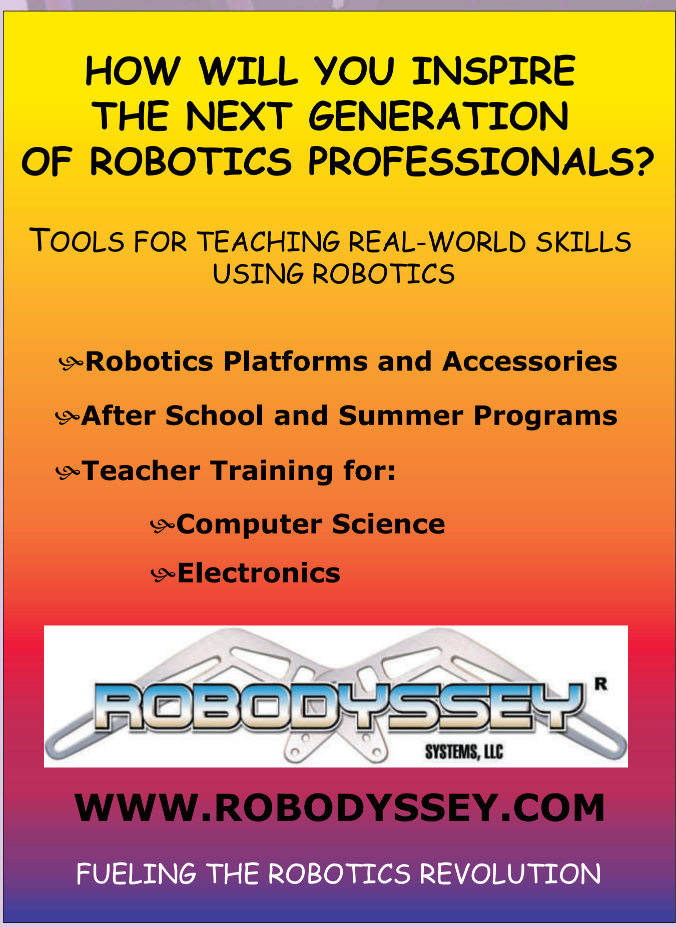
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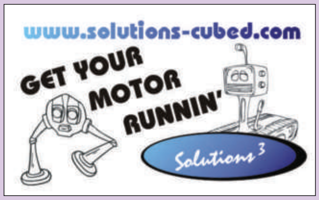

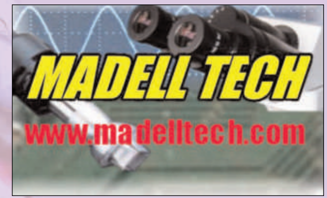

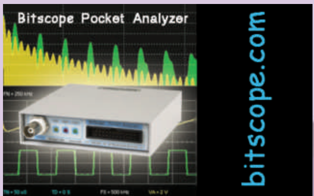

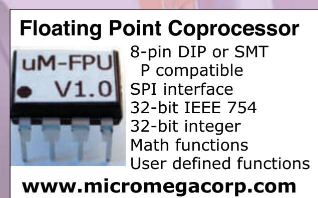

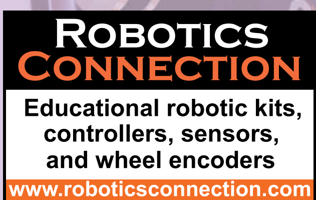

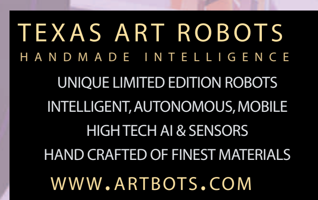

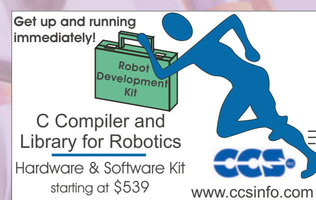

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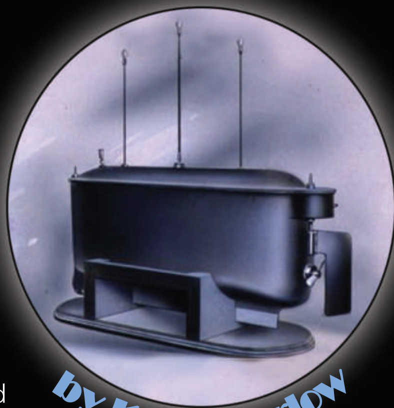
The World's First Robot

- Courtesy of Nikola Tesla -



by Kerry Barlow

I am sure that everyone who reads this magazine is aware of the Tesla coil. Studies and terminology in magnetic field strength are also attributed to legendary inventor Nikola Tesla. It may surprise many readers, however, to find out that Tesla was also the creator of the world's first teleoperated robot. This was not a charlatan's trick, nor was it a scheme conceived on paper and never produced. Tesla did, indeed, design and build a working robot. Even more amazing is that this robot was remotely operated without wires.

If this has not peaked your interest by now, let me tell you a few more startling facts of this early robotic device. In the proper terminology of the day and in Tesla's own words, this device was a tele-automated vehicle, and was built in at least two different forms. One of these was a boat and the second was a submersible vehicle — a submarine, by today's terminology. What truly makes this amazing is that the original patent date for this invention was on November 8, 1898 — 106 years ago!

Tesla's robot — either in boat or submarine form — was truly an amazing vessel. The basic unit was a steel, tub-shaped form with an internal power plant and rudder control. In addition, the boat had remotely operated lights onboard. Refer to the photo above for an outside look at this amazing submarine. Please note that Figure 1 is a modern example of the internal workings of the vessel, as created at the Belgrade Museum. In addition, Figure 1 does not show any of the receiver or escapement mechanisms.

The overall size of the vehicle is unknown by this author; one reference cites the boat as being as long as 30 feet. Regardless of the size, Tesla states that he had many working models.

Inside the vessel was a myriad of relays, coils, and clockwork gear mechanisms (see Figure 2). The main functions of the vessel were forward on and off, left and right steering, and — in the case of the boat — mast mounted lights on each side of the upper deck. In addition, the submarine must have had some form of submersible control, as well.

According to Tesla's autobiography, he began active work on building remotely controlled devices in 1893, although the concept had occurred to him earlier. During the next two or three years, he built several mechanisms to be actuated from a distance and showed them to laboratory visitors. Unfortunately, the destruction of his laboratory due to fire interrupted these activities. In 1896, Tesla wrote, "I designed a complete machine capable of a multitude of operations, but the consummation of my labors was delayed until 1897. When first shown in the beginning of 1898, it created such a sensation such as no other invention of mine has ever produced."

The basic patent was received in November of 1898, only after the patent examiner and chief had come to New York and witnessed the operation of the vessel. The examiner claimed it was unbelievable and was not willing to grant the patent without seeing the invention for himself first hand.

In early 1898, Tesla demonstrated his boat at an electrical exhibition in the recently completed Madison Square Garden. The boat was equipped with, as Tesla described, "a borrowed mind." Tesla wrote that he had cleverly devised a means of putting the audience at ease, encouraging onlookers to ask questions of the boat. For instance, in response to the question, "What is the cube root of 64?" lights on the boat flashed four times.

When a *New York Times* writer suggested that Tesla could make the boat submerge and carry dynamite as a weapon of war, the inventor exploded. Tesla quickly corrected the reporter, "You do not see there a wireless torpedo; you see there the first of a race of robots — mechanical men which will do the laborious work of the human race."

This is a very interesting statement from a genius of this caliber. Tesla was to refer in other ways to his plans for automata or robots. Tesla wrote that he also proposed to design an automated car which, left to itself, would perform a great variety of operations involving something akin to judgment. Conceiving of robots having many uses he believed that their greatest role would lie in peaceful service to humanity. Tesla later described his 1890s activity. "I treated the whole field broadly, not limiting myself to mechanisms controlled from a distance, but to machines possessed of their own intelligence. Since that time, I have advanced greatly in the evolution of the invention and think that the time is not distant when I shall show an automaton, which left to itself, will act as though possessed of reason and without willful control from the outside."

As mentioned above, the boat was a clever design of motors and clockwork gear mechanisms. The following quotes taken from Tesla's patent are insightful:

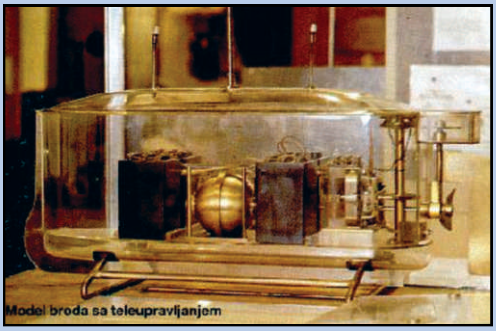


Figure 1. A re-creation on museum display.

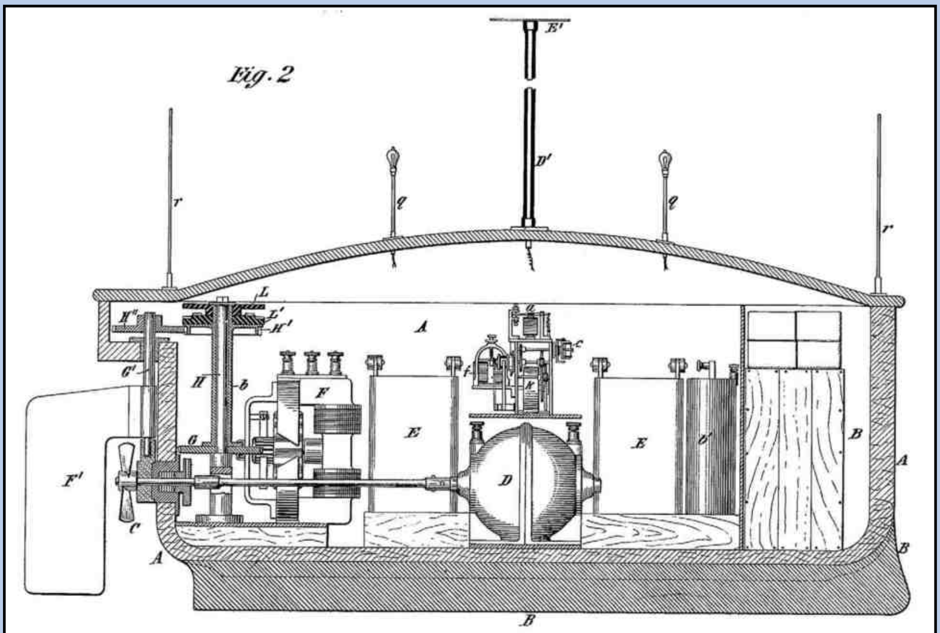
"The problem for which the invention forming the subject of my present application affords a complete and practicable solution is that of controlling from a given point the operation of the propelling-engines, the steering apparatus, and other mechanisms carried by a moving object — such as a boat or any floating vessel — whereby the course of such body or vessel may be directed and controlled from a distance and any device carried by the same brought into action at any desired time."

"I am enabled by the use of my invention to employ any means of propulsion to impart to the moving body or vessel the highest possible speed, to control the operation of its machinery, and to direct its movements from either a fixed point or from a body moving and changing direction however rapidly and to maintain this control over great distances without any artificial connection between the vessel and the apparatus governing its movements and without such restrictions as these must necessarily impose .... I require no intermediate wires, cables, or other form of electrical or mechanical connection with the object, save the natural media of space."

On extensive review of the patent and from period photographs, the operation of the vessel was quite ingenious. The boat had three motors and it is presumed that the submarine would have had additional motors to at least control the submersion. The first motor was for forward, the second motor for rudder control — both left and right — and the third motor would operate a clockwork brush mechanism that controlled the lights or any number of other circuits within the vessel.

A single motor drove the rudder control through a gear train mechanism. On reception of a sequence of pulses, the rudder motor was made to rotate clockwise or counterclockwise, thereby rotating the rudder. I have seen many modern toy radio control systems use this very same method. I wonder if toy manufacturers know this method was used many years before them?

Figure 2. One image from his US patent application.



The entire receiver section used a tuned circuit receptive to only one narrow frequency (see Figure 3). Tesla has claimed that he could have many hundreds of tuned circuits all operating on different frequencies and not interfering with one another. The actual reception of signal was performed by a device similar to what was used on telephone switchboards of the era. This consisted of a battery with its poles connected to two conducting terminals separated by a minute thickness of dielectric. In Tesla's words, "When an electrical disturbance reaches a circuit so arranged and adjusted, additional strain is put upon the insulating film, which gives way and allows passage of a current that can be utilized to operate any form of circuit controlling apparatus."

This dielectric was known to break down easily after a period of use. Tesla designed a special dielectric system using powder inside a cylinder. This was periodically rotated or flipped automatically onboard the vessel to restore functionality to the system. With this new design, Tesla stated that many thousands of signal receptions would be maintained in a reliable method. There is quite an extensive description of this in the patent and I encourage readers to review this.

After the detector received a signal, a series of gears and an escapement system were used to count the signals and direct battery power to the various motors. Readers will note that this was the same method used in the early AM radio control aircraft of our so-called modern generation. Once again, considerable detail of the entire gear train, escapement mechanism, and clockwork system is described in Tesla's patent.

A simple understanding of this, however, shows that Tesla used varying length pulses of frequency from his transmitter to force the receiver to move its relays in various manners. According to the patent, Tesla could do all of the following, all as separate entities: drive forward, drive forward

Courtesy of Nikola Tesla

and left at 45 degrees, drive forward and left at full travel rudder, drive right at 45 degrees and forward, and drive right and forward at full rudder deflection. Additionally, with the motor in neutral, he could send certain pulses and activate his accessory motor. This motor would once again count pulses and control the onboard lights in a certain manner. He could tell the lights to turn on or off as singles or in pairs. Also, he could tell the left light to come on when the vessel was going left and the right light to come on when the vessel was going right.

I would go into the detail and workings of this escapement system, however the information is quite technical and is contained in over five pages of patent text. Once again, I encourage the reader to review the patent itself for further details.

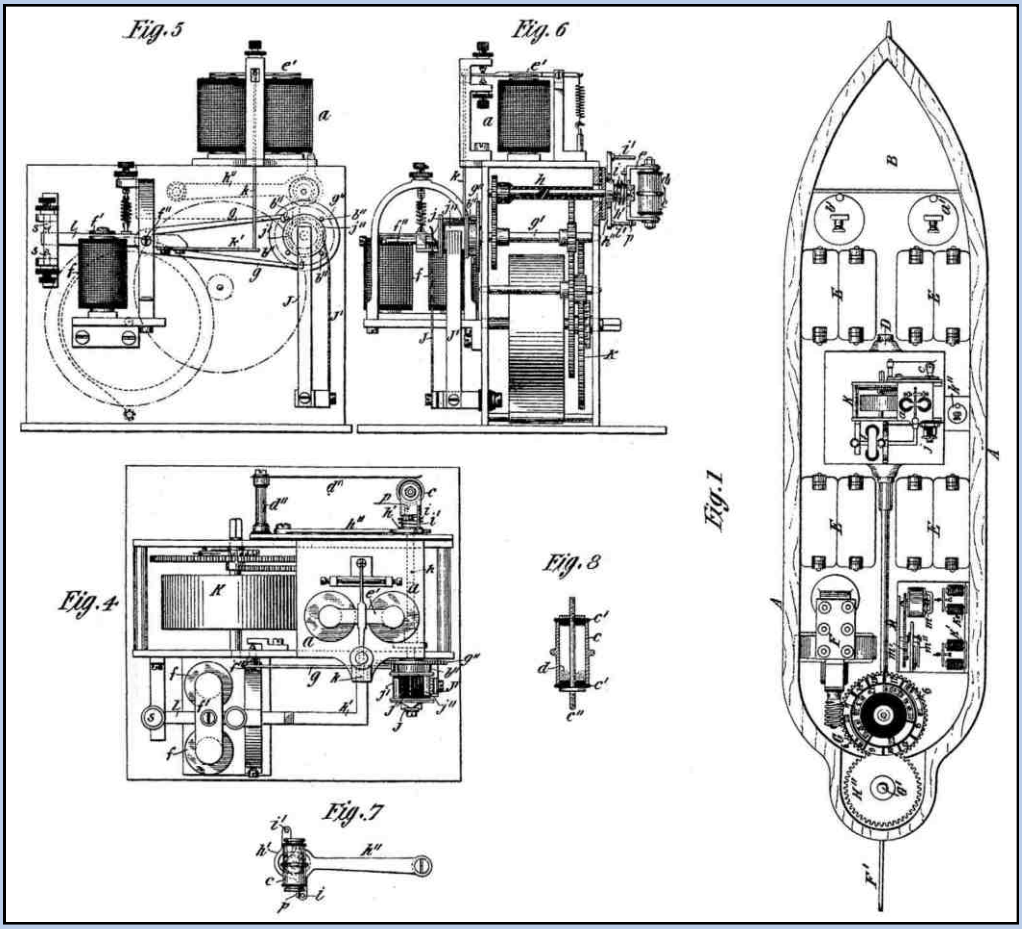
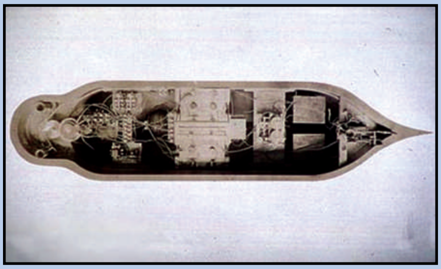


Figure 3. More drawings from his patent on the internal workings of the submarine.

Tesla always had far reaching visions for his inventions. His patents also included specifications for a torpedo boat without a crew. Six 14-foot torpedoes were to be placed vertically in two rows so that, when one was discharged, another would fall into its place. It is unclear if this torpedo boat was shown at Madison Square Garden or not. From the reference to the reporter by Tesla, it is possible that this torpedo boat was shown in early 1898.

Tesla had advised the Navy that he thought such a boat could be built for around $50,000.00. When word of this got out, he received a letter from Mark Twain which read, "Have you Austrian and English patents on that destructive terror which you have been inventing? If so, won't you set a price upon them and concession me

Figure 4. Top view of Tesla's R/C boat.



to sell them?"

Unfortunately, nothing ever came of this. Tesla was well known for not pursuing many ideas fully. The inventor always claimed he did not have enough time to produce all the many inventions he had ideas for. It must be remembered that many AC motors, generators, coils, lights, and other working devices were sold and patented by Tesla through Westinghouse. One final noteworthy item eventually follows from Tesla's robotic work. Tesla stated that a second idea was implemented in 1898, but was not issued a patent until later.

In 1903, in an attempt to refine his achievements, Tesla acquired a patent for a method of signaling. This was based upon his earlier work in tele-automation and robotics. This new patent used a group of coordinated tuning devices responsive to a combination of several radio waves of completely different frequencies. What this patent referred to in detail was a system whereby two or more entirely different frequencies must be received at the same time by a receiver before a relay would be activated. Tesla stated that any number of these tuned frequencies may be used and it would work as effectively as a tumbler lock.

In the later half of the 20th century, it has been written that many computer designers have been shocked to stumble upon Tesla's basic patent for the basic logical "AND" circuit used in all modern computers. Although Tesla used AC signals and modern computers use DC signals, the effect was identical. This was the theory of using two or more inputs to produce an output.

Nikola Tesla's tele-automated vessels were truly amazing feats of achievement. It is little wonder that the public was amazed, astounded, and actually fearful of such a device when they saw it in operation. Although he is seldom recognized for this accomplishment, Tesla's vessel was literally the birth of robotics. SV

References and Patents

Patent 613,809 — Method of and apparatus for controlling mechanism of moving vessels.

Patent 723,188 — Method of signaling.

Tesla, Man Out of Time, by Margaret Cheney 1993, Barnes and Noble.

The Fantastic Inventions of Nikola Tesla, by Nikola Tesla and David Hatcher Childress, 1993, Adventures Unlimited.

Tesla Belgrade Museum website:
www.yurope.com/org/tesla/uvode.htm

Second Museum link:
www.tesla-museum.org/en_meni/menis.htm

US patent office website:
www.uspto.gov/patft/index.html

More Robotics OUTSIDE THE BOX!

by Gordon McComb

In last month's "Robotics Resources," we talked about "thinking outside the box," finding construction materials that — at first glance — don't look like suitable robot building parts. Whether it's a toy, a sewing accessory, or a piece of hardware designed for use in shelving, you could discover a great new use for something simply by looking beyond its intended use.

Last month, we began with a look at out-of-the-ordinary materials, including transfer films, store fixtures (one of my favorites), paper and plastic laminates, jewelry "findings," woodcraft materials, restaurant supplies, and science goodies.

In this month's column, we'll look at more retailers that carry merchandise which can be pressed into service for building bots. These retailers include sporting goods stores, arts and crafts outlets, office supply stores, and more. Scan their product offerings for ideas. Obviously, this list doesn't represent every place that sells something useful for robotics. The idea here is to get you thinking outside the box!

Office Supplies

What do office supplies and robots have in common? That depends on how you look at the products carried by office supply stores. Consider alternative uses for such items as:

- Packing tape, non-permanent adhesives, reinforced strapping tape, double-sided tapes. Adhesive tape can be used to attach small parts to your robot and is also useful for "temporary" constructions. Double-sided foam tape is particularly handy for mounting R/C servos and even small caster wheels. Reinforced strapping tape is very strong, yet lightweight, and can be used to hold motors and other parts to a frame while you experiment with different designs.

- Inkjet transfer film. Use the film to make designs for your robot. Print the design on the film, then transfer the artwork to the robot (the film package provides instructions).

- Plastic for spiral binding machines. The plastic covers are thin and pliable and great for the outer skin of your bot. The plastic combs can be used for wire management (keeping all the wires together), bumpers, and more.

- Magnetic sign sheets. These are basically magnets in sheet form. You can cut out shapes with a knife or scissors. I've had success cutting out little 1/4" discs and then mounting them on the side of a wheel. By using a Hall Effect sensor (sensitive to magnetic fields), it's possible to count the revolutions of the wheel.

These chain store listings are representative of office supply stores worldwide. These resources offer online sales and you can browse their web catalogs for ideas.

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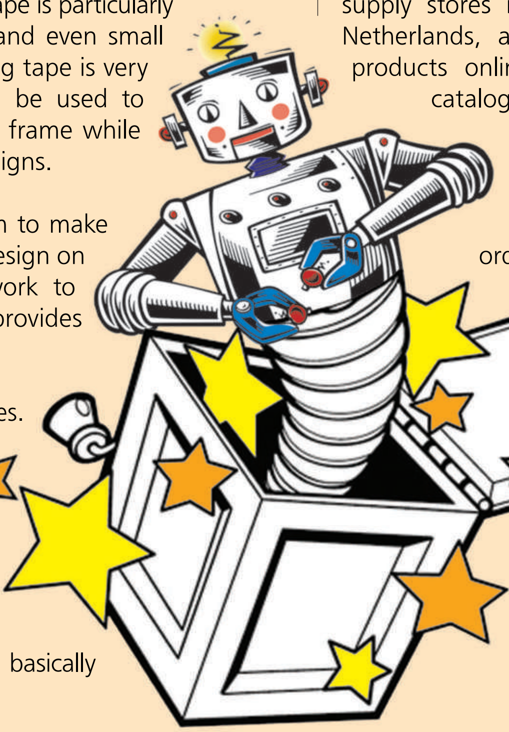
www.staples.com

Staples operates a couple (okay, some 1,300) of office supply stores in the US, Canada, Germany, the UK, the Netherlands, and Portugal. They also sell most of their products online from their website and through direct catalog sales. Refer to the website for a store locator.



Arts and Crafts

Here, you'll find retail stores (online, mail order, and walk-in) that specialize in arts and crafts, as well as professional and amateur artist supplies. Products run the gamut from glue guns and liquid adhesives, small parts for doll houses and jewelry making, paints, paint brushes and airbrushes, fixatives (use for stabilizing water-slide decals), foam board and other substrates, small balsa and metal pieces (e.g., J & S Engineering) for construction, sewing notions (fusible tape, plastic needlepoint cloth), small plastic

display boxes (use as parts containers or cheap electronics housings), polymer clay, casting materials, and more!

Be sure to check out the store's selection of foam board, which is made by sandwiching a piece of foam between two sheets of thick paper. Most foam board you'll find in arts and crafts stores is 1/4" thick and available in colors. Use a knife or small jigsaw blade to cut it. You can use pieces of foam board to make down-and-dirty robot platforms. For a small and lightweight robot, you don't need heavy wood, metal, or plastic.

Activa Products, Inc.
www.activaproducts.com

Arts and crafts supplies. Includes casting and mold making supplies.

ArtSuppliesOnline.com
www.artsuppliesonline.com

Art supplies: craft boards (such as foam board), plastics, adhesives, and lots more. Their online store lets you browse by category or search for specific products by name or brand.

Art Supply Warehouse
www.aswexpress.com

Artists' accessories, brushes, foam boards, and paints.

Clotilde, Inc.
www.clotilde.com

Online and mail order (printed catalog) of sewing and quilting supplies. Look over things like fusing tape (partially melts when heated), small tools, rotary cutters (useful for foam board and other lightweight laminates), and elastic material.

Crafter's Market
www.craftersmarket.net

Crafts, including knitting and needlepoint. Use the plastic needlepoint "canvas" for making grilles, bumpers, and other parts for your robot. Local and online stores.

Dick Blick Art Materials
www.dickblick.com

Complete line of craft materials and art supplies. Also local stores (predominately in the Midwest and Great Lakes areas of the US).

Dixie Art & Airbrush Supplies
www.dixieart.com

Airbrushes and compressors, general art supplies.

Fastech of Jacksonville, Inc.
www.hookandloop.com

VELCRO® distributor. Online sales.

FIGURE 1. Arts and crafts supplies at **ArtSuppliesOnline.com**

FLAX Art & Design
www.flaxart.com

Art supplies: adhesives, paints, substrates, crafts, and drafting.

Hobby Lobby
www.hobbylobby.com

Hobby Lobby is not to be confused with Hobby Lobby, International. The former is a chain of arts and crafts stores; the latter is a mail order retailer of hobby R/C components. Hobby Lobby locations can be found throughout the central US.

Hygloss Products, Inc.
www.hygloss.com

Manufacturer of children's arts and crafts supplies. These include specialty paper, pre-cut Styrofoam pieces, and foam sheets.

Michaels Stores, Inc.
www.michaels.com

Michaels sells arts and crafts items, both online and in some stores across the North America and Puerto Rico — they're the largest such retailer, in fact.

MisterArt
www.misterart.com

This site bills itself as the, "world's largest online discount art supply store." This seems to be true; they have a lot of stuff — quite a bit of supplies for paint artists, as well as foam core, precision tools, and adhesives.

Nancy's Notions
www.nancysnotions.com

Online and mail order (printed catalog available) of sewing supplies. Let your imagination run wild.

Nasco.eNasco
www.enasco.com

eNasco is the online component of NASCO, a mail order catalog offering some 60,000 educational supplies. The company also sells farm and ranch supplies (no kidding), construction toys, and books. Outlet stores are in Fort Atkinson, WI and Modesto, CA.

Polymer Clay Express
www.polymerclayexpress.com

Polymer Clay Express is an online retailer of unusual and useful art supply materials, including plastic

shrink art, WireForm wire mesh, casting and modeling clay, Lazertran transfer sheets, and holographic metal foils. Who says robots should look dull!

Quincy
www.quincyshop.com
Art supplies, craft kits, tin toys (Futurama), miscellaneous toys that can be hacked apart to make robots.

Reuel's
www.reuels.com
Art and framing supply. Local store and online store. Products include adhesives, airbrushes, crafts supplies, sculpting supplies, and foam board.

T. N. Lawrence & Son, Ltd.
www.lawrence.co.uk
Lawrence Art Materials offers online buying of arts and crafts supplies. Their product line emphasizes painting and reproduction supplies (acrylics, brushes, easels, and what-not), but they also offer a number of potentially useful artifacts for bot building. It's all in how you look at things. Here are some ideas:

• Intaglio printing plates include copper or zinc sheet metal. These sheets can be used in the construction or embellishment of robot bodies. Available in different thicknesses (1-2 mm is average) and sizes. The smaller sheets are quite affordable.
• Fluorescent acrylics can be used to paint your robot in vivid colors. Bright colors can be used when building robot teams for competitions (depending on vision systems, of course).

• Lazertran transfer paper lets you print in full color and transfer the image to almost any surface. Use it for your robot's paint job, to label a control panel, and more. Visit **www.lazertran.com**

• Student quality rollers, used to press on glued laminates (thin metal over wood or plastic), rub-on lettering, and in any other job where gentle but firm pressure must be applied.

• Engraving plastic is a thin, semi-flexible plastic sheet that can be used for building laminates.

Armatures and Doll Parts

Online retail stores that specialize in doll and Teddy bear making parts are listed here. This includes something known as armatures, which are used in dolls and puppets to replicate bone joints. Armatures can be bent to a variety of shapes and act as a kind of skeleton. If the armatures are strong enough — metal or wood, for example — you could use them to fashion the frame for a walking robot. Lighter armatures can be used for less rigorous tasks, like small grippers. Other doll parts you can use in your robots include eyes, noses, and "body foam" (soft and pliable, but thick). These are useful if you are marking an animal- or human-like robot. Some doll parts stores also carry sound modules, a few of which let you record your own voice. Others play a simple tune or make animal sounds. Use these to build "wild-and-wacky wobots."

Armaverse Armatures
www.armaverse.com
Ball-and-socket doll armatures. Sells individual pieces and kits of parts.

Bear Ingredients
www.bearingredients.com
Teddy bear supplies: eyes and joints.

Chatsco Distributions
www.chatsco.com
Teddy bear and doll body parts: eyes, noses, squeakers, whiskers, voice modules.

Disco Joints and Teddies
www.discojoints.on.ca
Teddy bear supplies, including disk joints, screw joints, eyes, and noses.

EZ Pose Flexible Doll Bodies
www.ezpose.com
Professional doll artist Sandi Patterson sells a line of posable doll bodies that — with a bit of work, servos, and batteries — could make a nightmare straight out of *The Twilight Zone*. The

bodies are soft fabric and foam over bendable armature wire. Attach a head and you've got your own Talking Tina!

Spare Bear Parts
www.sparebear.com

Teddy bear parts, including eyes.

Teddy Bear Stuff
www.teddybearstuff.com

Teddy bear supplies, such as eyes and foam.

Taxidermy Supplies

Taxidermists use various artificial body parts to stuff elk, deer, fish, and other game that hunters bag. Of particular interest are eyes, casting materials, foam, and even fake fur. These products are especially useful if you are building an ani-bot — a robot made to look like a cuddly bear, squirrel, or weasel.

Expanding foam — available from many taxidermy supply sources — is especially interesting. You spray the foam out of a can; upon contact with air, the foam expands to several times its original volume. Once dry, the foam can be sanded and carved. Uses of expanding foam include making body parts for a larger robot and forming simple molds.

Jim Allred Taxidermy Supply
www.jimallred.com

Taxidermy supplies: eyes (for humanoid or animal robots) and foam.

McKenzie Taxidermy Supply
www.mckenziesp.com

Stuff for when you bag that ol' robot. McKenzie sells taxidermy supplies, of which things like eyes, casting materials, and carvable foam are note-worthy to the robot constructionist.

Van Dyke's Taxidermy
www.vandykestaxidermy.com

Check out their carving foam, various kinds of glass eyes, and assorted unusual materials. Their foam block is easy to work with and can be shaped with simple tools.

Miscellaneous Sources

Last, but certainly not least, be sure to check out the wares in these additional sources. They include sporting goods stores, appliance repair outlets, and even farm supplies.

Apogee Components, Inc.
www.apogeerockets.com

Model rocketry stuff. For building supplies: epoxy clay, cardboard tubes, and parachutes (in case you build a hang gliding robot). Keeping the weight down is critical in model rockets. These same products make for ideal light-weight components for small robots.

Big 5 Sporting Goods
www.big5sportinggoods.com

Sporting goods chain store. Use the store locator or search for product information. Look for things like small ping pong balls you can use for caster wheels or nylon fishing line for making actuator cables.

FarmTek
www.farmtek.com

Dispel the images of a John Deere robot — this catalog is useful for the non-tractor goodies it offers, such as fasteners, springs, clamps, tubing, PVC, conduit, tools, and lots more.

Mending Shed
www.mendingshed.com

Appliance parts. You'd be surprised what neat things you can find: gears, small DC gearmotors, levers, cranks, cams, belts, and lots more. Study the catalog for inspiration.

Nelson Appliance Repair, Inc.
www.nelsonappliance.com

Another source for replacement appliance parts.

Sports Authority, Inc.
www.thesportsauthority.com

Major sporting goods chain. Retail stores and online shopping. See the listing for Big 5 for some ideas on what to look for. SV

ABOUT THE AUTHOR

*Gordon McComb is the author of several best sellers on robotics. You're welcome to visit his site at **www.budgetrobotics.com** He can also be reached at bots@robotoid.com*

AUTONOMOUS ROBOTS *Made Simple*

by Tom Brusehaver

I am a software person, so having a reliable device to program really helps. I had several goals in mind when I started this project:

1. *Reliable* — if I was going to do software development — not robot repair — the robot has to work every time it is turned on.

2. *Not too big* — Big robots are more work; they need bigger batteries, a bigger structure, and bigger motor controllers.

3. *Not too small* — I want space to add additional sensors and interesting hardware.

4. *One central CPU*, with capability for additional CPUs.

I have built a robot that meets all these goals and has been a real pleasure to work with.

CPU HARDWARE

I decided to use the Handy Board (**http://handyboard.com**) that Fred Martin designed. This board has many features that make it a nice starting platform. It has built-in motor controllers for up to four motors, Polaroid ultrasonic sensor controller, LCD display, battery-backed RAM, 40 kHz IR, two user push buttons, a user knob (pot), servo output, many sensor inputs, and all the libraries to drive these devices. Normally, it has built-in Ni-Cad batteries, which can drive most small motors.

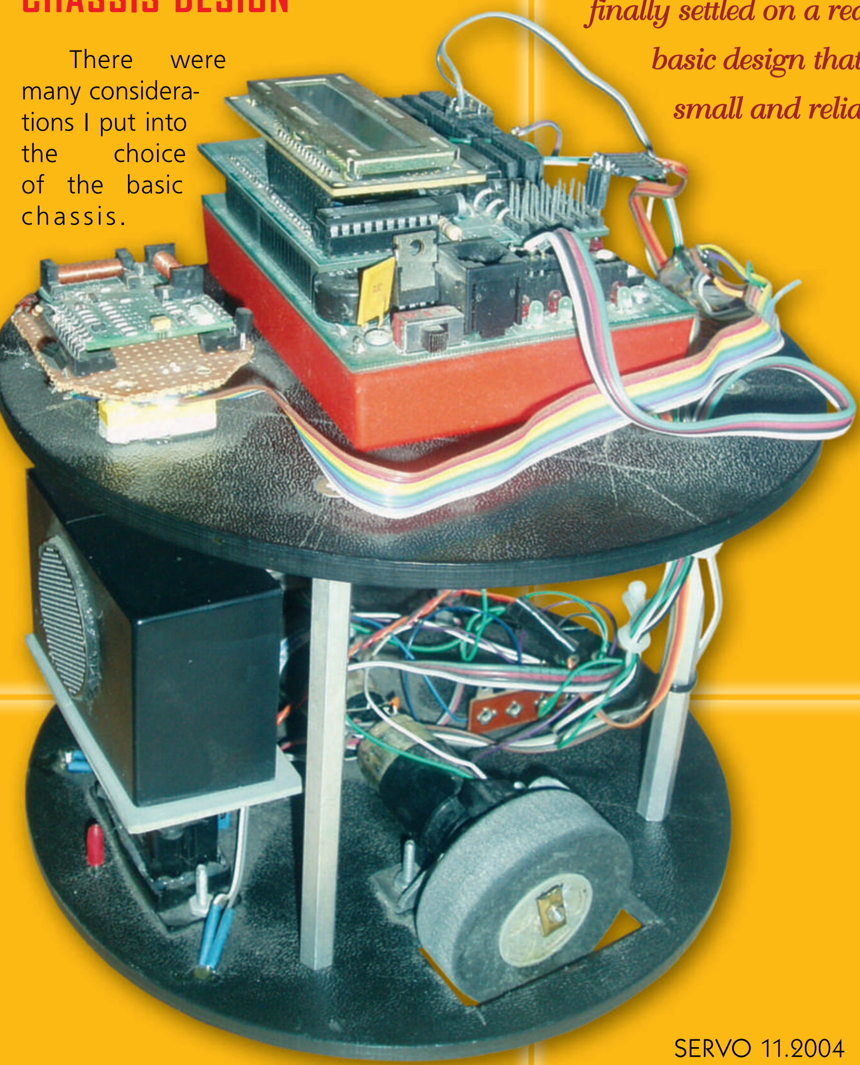
The board is similar to the board discussed in the book *Mobile Robots: Inspiration to Implementation* by Joseph Jones and Anita Flynn; many of the example programs can be adapted to work on this board. There is also a wealth of software for the MIT 6.270 board that the Handy Board is based around.

I also wanted to use a compass module as an aid to navigation. I chose the Precision Navigation Vector2X compass. This compass module outputs either direct degrees measured, or the relative magnetic strength in two directions. It outputs using the Motorola SPI synchronous serial protocol. The library for the compass is at the Handy Board website.

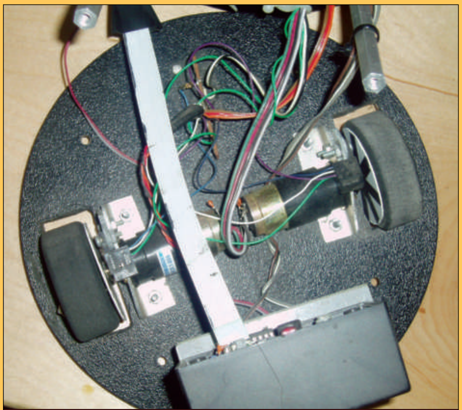
CHASSIS DESIGN

There were many considerations I put into the choice of the basic chassis.

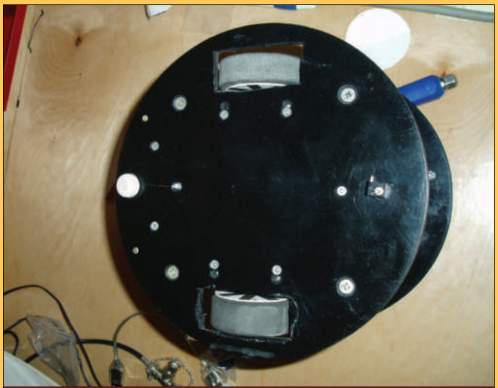
Over the years, I have built several autonomous robots — many of them meant to be experimental platforms and some special purpose robots. I usually spent more time building than programming because I went overboard on some feature I thought I needed, but usually never used. I finally settled on a really basic design that is small and reliable.



(To the right) Side view, showing the brass tubing bent over attached to the wheel with the threaded rod, the Handy Board on top, with the compass and sonar in the front.



Base, showing the motor placement and the mounting of the sonar device.



Detail of the bottom, showing the countersunk screws, the furniture skid, the CdS cells (far left), and the light source (left center).

I thought the chassis should fit in a cubic foot, since this would allow me ample space on my workbench to program and test the code I was writing. I decided on center drive wheels that counter-rotate for steering to make navigation easier. Since the Handy Board has an LCD display on it, the CPU needed to be visible most of the time. Making the basic robot round is a really good idea. If the robot misjudges a corner or opening, the round shape will usually allow the robot to bump and slide off.

My wife is a potter; she throws clay pots on a wheel. To make things easier to change from one pot to another, she buys round boards that slip on the wheel and works the clay on top of those. These boards are called bats and can be purchased at clay supply stores. One day, she got a plastic bat and I knew it was perfect for a robot chassis.

I bought two 8" Plasti-Bat®s: one for the top and one for mounting the motors. The bats are available with or without holes. I chose to buy the ones with holes, since I thought I could use the holes to align things. The holes are nice for running wires from one level to another. There is a textured side and a smooth side to the bats. I chose to put the textured side up, but it does collect a little more dust when running on the floor. I found some 5 inch aluminum stand-offs — probably surplus, but using a 2 inch and a 3 inch would be equally fine with a short, threaded rod to join them. Using aluminum is ideal, since it is light weight and non-magnetic. These stand-offs are threaded all the way through with 8-32 threads — a common size.

Originally, I found some very inexpensive geared motors. These worked well and I probably would still be using them, but I recently found some very nice precision geared motors. The precision geared motors are quieter, use less current, and start at a lower voltage. Currently, All Electronics has some similar motors — part number DCM-211 (**www.allelectronics.com/**).

The wheels I chose are light weight model aircraft tires, 2-1/4" diameter. The tires don't provide much ground clearance, so the robot doesn't wobble too much. The model aircraft tires have a standard 5/32" hole, making mounting quite flexible. They have a plastic hub and a closed cell foam rubber tire.

CHASSIS ASSEMBLY

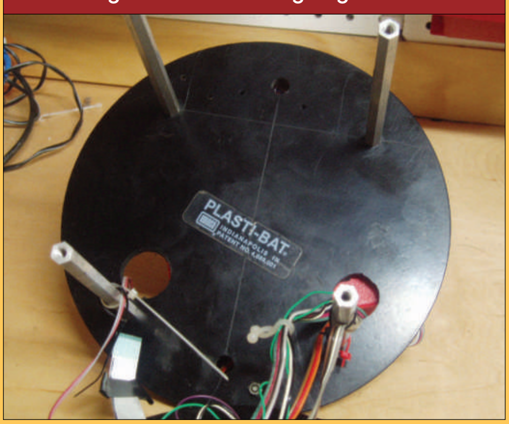
I laid out the bottom bat to hold the motors and some sensors. The two holes needed to be large enough for the whole wheel to pass through, in addition to providing some clearance if the tires squish or flex. Cutting the plastic bat was done using a Dremel tool, but a saber saw with a fine toothed blade would have worked better. The plastic cuts very easily, even with coarse blades. Cutting at a slow speed to prevent the plastic from melting and gumming up the blade will actually be quicker.

I aligned the top and bottom parts for drilling the holes for the stand-offs. I clamped both bats together and drilled them at the same time to insure that the holes line up. One accessory I wanted early on was a compass, so I used all aluminum hardware to minimize interference. I was able to buy 8-32 aluminum countersunk screws at the hobby shop; they are used for radio controlled cars.

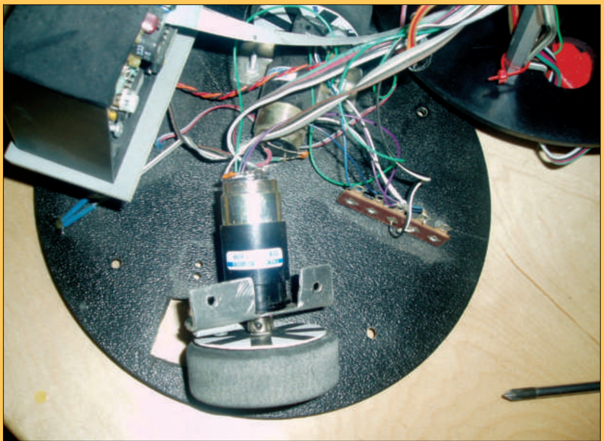
The bottom didn't have much clearance, so using countersunk screws became a requirement. It is really easy to countersink the plastic using a countersink bit — even a larger (i.e., 3/8") bit would work. Using countersunk screws does give the robot a more professional look, too.

To mount the original gear motors, I put the flat, bottom surface against the bottom bat. I cut out two 1/2" x 4" x 0.032" pieces of aluminum — one for each motor. I drilled a 1/8" hole in each end and wrapped it around the gearbox. Then, I drilled in the bat on each end for mounting screws. For mounting the precision motors, I layed out a pattern on some 0.063 aluminum and cut two identical pieces.

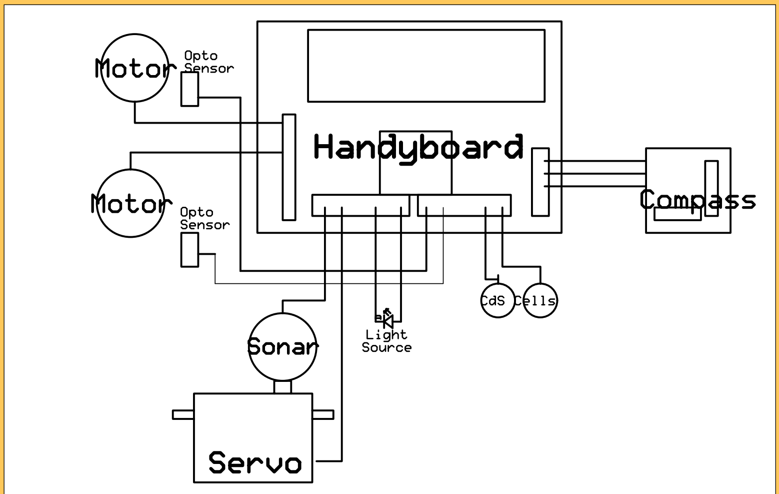
Top, showing the stand-offs; the smaller holes are originals used for aligning the center.



Front, showing the sonar mounting, the servo, and some of the wheel details.



Top motor detail, showing some of the wiring, the sonar, and the terminal strip.



System block diagram.

Bending aluminum takes care. Hardened aluminum — like 2024-T3 or 6061-T6 — requires a setback when bending. A sharp bend will cause the aluminum to crack. Aluminum also has a grain that can be seen in the light. Tighter bends can be made perpendicular to the grain.

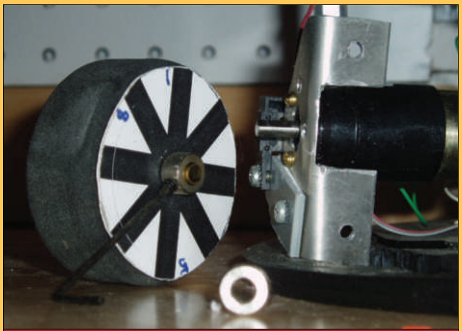
To attach the wheels to the motors, I needed a way to adapt the shaft diameter to the wheel hole size. Brass tubing (available at most hobby stores) is ideal for making adapters like this. The metric shaft of the precision motor fit loosely in some 5/32" outside diameter tubing, which fit snugly in the center of the wheels. I left the tubing about 1/2" too long on the outside and used a 5/32" du-bro collect near the motor.

When the collect was tightened, it squashed the brass tube to the shape of the shaft. I was careful to align the set screw of the collect with the flat on the motor shaft. The excess shaft sticking out of the wheel was flattened with pliers and bent over. I drilled a 3/32" hole in the tube and the hub of the wheel. Through this hole I put a 2-56 x 1" threaded rod and tightened some nuts around it. This provides positive wheel movement.

When I bought the Handy Board kit, it came with some optical sensors. I wanted to use these optical sensors for wheel encoders. I added a piece of plastic on the wheel side of the motor mount to allow attaching these sensors. For the actual encoder disk, I drew four intersecting lines in Xfig (**www.xfig.org**) and printed them out on a laser printer. These pieces of paper were glued to a plastic disk, slightly smaller than the wheel. I drilled a hole 5/32" diameter in the center of the disk and sandwiched it between the collect and the wheel with a little silicon glue.

I used 4-40 screws to attach all the smaller items to the bottom. The precision motors required 2.5 mm mounting screws to attach the motor to the bracket. All screws that penetrate the bottom are countersunk. The bats are about 1/4" thick, so countersinking too far is not a problem.

The chassis will vibrate constantly when the robot is in motion, so all screws are required to be locked in place.



Motor mount bracket, motor, and wheel showing collect and brass tubing. The stripes are printed on paper and glued to a plastic backing.

Lock washers, lock nuts, and glues will allow the screws to remain tight with their nut. Lock washers are what I use most, especially for smaller nuts. They are available with inside teeth, outside teeth, or split round washers. Lock nuts — either all metal or nylon inserts — are also good choices. Lock-Tite and similar thread locking liquids are available in several choices: permanent, non-permanent, and with various temperature ranges. In a pinch, putting Super-Glue or other CA (Cyanoacrylate) glue on the threads will lock the two together.

Almost any motor used will require some kind of capacitor across the terminals. This capacitor will reduce the noise that may be induced into the computer. Usually a 0.1 or 0.01 µF capacitor connected across the motor terminals will do the trick. If the robot doesn't seem to work after a while, check the capacitor; it may have broken.

On the bottom bat, I added some additional sensors. I mounted two CdS photocells, a servo with the Polaroid ultrasonic sensor, and a light source along the front. I also mounted a barrier strip in the rear. The chassis was a little wobbly, so I found some furniture skids from the hardware store and put them at either end. For the front skid, I put some black conductive foam to act as a spring and damper. I used the plastic cover that came with the skid to keep it attached.

Mounting the Polaroid ultrasonic sensor was a challenge. I wanted it on the servo so the robot could "look around." I used the servo arm that came with the servo to attach to a piece of 1/8" plastic. The threaded screws that came with the servo were self-tapped into the plastic. I then mounted a project box on this piece of plastic using 4-40 screws. The project box was cut out to mount the ultrasonic transducer and the board was mounted inside. The transducer was attached to the box using clear silicon adhesive.

Once everything was attached, I screwed the long stand-offs on the bottom using the 8-32 countersunk screws. The top was attached using the same 8-32 countersunk aluminum screws. I drilled large holes in the top, near the center rear for running wires from the bottom sensors and motors to the top where the computer will be mounted.

BRAINS

I mounted the Handy Board using VELCRO® in the rear half of the top bat. The Handy Board comes with the batteries in a plastic box that the CPU board mounted above. There are no bolt holes or anything else that would would make attaching it easy. I also thought that maybe I would like to remove the Handy Board on occasion, so using the VELCRO allows change without major surgery.

I mounted the compass at the front of the top bat. To make the compass most accurate, there cannot be other ferrous metal parts near the compass module. That is why all the metal parts near the top are aluminum. The compass module is almost a DIP package, but is too wide. I used a standard 28-pin DIP socket — cut in half and widened — in a perfboard to mount the module. I used hot glue to attach some LEGOs to the bat and the plug parts to the compass module perfboard.

WIRING

Using the Handy Board, the wiring is quite easy. Separate wires to each of the motors, the servo, the ultrasonic sensor, and all other sensors need to be run to the computer. The barrier strip is used as a breaking point for the motor wiring and the CdS sensors in such a way that, if something is changed later, the short wiring on the bottom bat is all that needs changing.

All wires should be long enough to be attached to one of the stand-offs. Using a zip tie or other wrap will keep the wiring neat and reliable. With the wires hanging loose, they tend to get hooked on things and eventually break. Other options for attaching the wiring to the stand-offs would include bread ties, heat shrink tubing, and scrap wire.

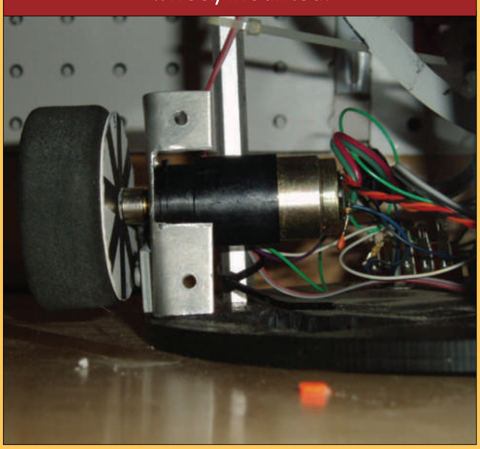
To connect to the Handy Board, the 0.1" header strips are used. The header strips supply power and ground, allowing sensors to have pull up or pull down, as well as a voltage supply. The optical sensors need a supply voltage for the LED and a current limiting resistor. Using individual connections is best, allowing for easier maintenance and assured orientation.

The sonar has a fairly stiff ribbon wire. There is a special connector needed for this. The Handy Board expansion board has the proper connector, but — using careful connections — the stock Handy Board can support the Polaroid sonar. This wire is about the right length for this chassis.

Some of the wiring should be done while the top and bottom are

Top view, showing VELCRO that holds the Handy Board, the compass, and the wiring through the top.

Wheel, mounted.



separated. It is much easier to wire the motors and sensors on the bottom bat before assembling to the top. "Dry fitting" can be done, to get the proper wire length. Assembly and disassembly of the chassis should be quite easy with the proper tools.

SOFTWARE

Most of the software to develop on the Handy Board is available on the Handy Board web page. The interactive C (ICC) compiler and all of the libraries and documentation for them are available. IC is available for Windows, DOS, Mac, and, of course, Unix — including Linux. The libraries are loaded to the Handy Board using IC and all the memory is managed for the run time through IC. IC allows interactive testing. To test the motors with the robot up on blocks from an IC prompt, enter the C statement:

```
motor(1,10);
```

This sends the command to the Handy Board to start the motor plugged into slot 1 at the speed of 10. Sometimes, the motors are plugged in wrong. Using this interactive testing helps insure that the basics are assembled correctly before proceeding to more complex programs.

Testing the motors, using the fd() and bk() to insure the motors are wired properly will make the programming easier. Enter fd(1); at the IC prompt and the motor connected to the motor 1 port should spin so the robot would move forward. If the motor spins incorrectly, it is easy to unplug the motor at the Handy Board and reverse it. Test the other motor the same way.

Testing the sensors can be done the same way. Using IC and entering commands, such as:

```
printf("%d\n",analog(5));
```

will read the photocell on the bottom of the bottom bat and display the results on the LCD display. The LCD display is one of the Handy Board's strong points, allowing debugging to happen while the robot is in motion.

I have written a sample program that will drive the robot forward until the sonar sensor detects something less than 16 inches away; then, the robot will pause, turn the sonar both ways looking for the most open direction, then turn to face that way and drive on through. You can download a copy of the sample program from the *SERVO Magazine* website, at **www.servomagazine.com**

I am also working on some mapping software to see if this robot can map out a room using the sonar, compass, and wheel encoders while driving around.

The design has been very robust. I have been able to use this robot for many experiments and rarely have to do more than charge the batteries. The design has been flexible. When I changed motors, drilled a couple more holes, and wired up the new motors, the same old software kept working, but the robot was quieter. **SV**

GEERHEAD

by David Geer
geercom@alltel.net

Just come a little bit closer and I GOTCHA!

Schilling Robotics — How Did Jacques Cousteau Get Along Without Them?!

Plus, a look back at Thor, Schillings' early contribution to the Robot Wars!

Schilling Robotics is a world class, world-spanning supplier of undersea manipulator arms and Remotely Operated Vehicles (ROVs) for underwater recovery operations. It started out providing remote controlled manipulator arms for ROVs about eight years ago and recently began supplying one-of-a-kind ROVs brand named Quest about two years ago.

The Quest ROVs are derived from unique new technologies developed by Schilling that scream to be mentioned. Quest ROVs are run by a very precise control system with its own modules of automatic control that no one else in the industry can offer.

"STA-tion. STATION!"

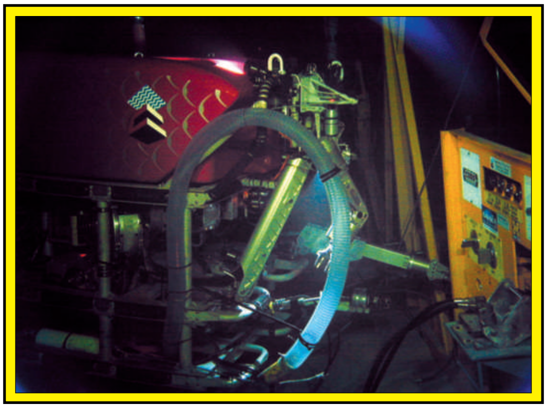
No, not the future-space roboticist creature twins from the movie *Bill and Ted's Bogus Journey*, but rather Station Keeping, the undersea technical miracle. One of the most important, most sophisticated modules is the Station Keeping mode. In this mode, a vast array of sensors collects data that is used to make the ROV perform functions relative to its sea floor position.

For example, an ROV may need to "fly" up to a well head on the sea floor. The ROV's pilot uses his joystick to maneuver the ROV manually against the water currents to maintain position. The Quest uses sensors including one that measures the ROV's velocity and direction relative to the sea floor and maintains this positioning automatically.

As Schilling put it, the trouble a pilot might have staying in place is comparable to the difficulty that a helicopter pilot might have staying close to a building in air currents and wind without hitting the building or moving too far away.

* Unless otherwise noted, all photos are courtesy of Schilling Robotics. *

Fly Like an ROV



The Quest vehicle powers the Coil Tube Drill with its onboard hydraulic power unit and operates the CTD control valves with its manipulators.

Schilling's snake-like CONAN manipulator arm.

Other modules or modes enable the ROV to fly along trajectories that have been mapped out, relative to the ROV's current position or station. The ROV can be parallel to a row of valve handles and move automatically to anyone of the valve handles down the line. This enables higher level commands from the pilot and smoother operational control.

The maneuverability and accuracy of flight of the Quest ROVs are not affected by underwater visibility. When the soggy bottom of the sea is stirred up, the ROV doesn't have to quit working.

The Quest comes in models that operate down to 6,500 meters underwater. The deepest flying one they have actually built — so far — goes down to 4,000 meters. The 4,000 meter depth Quest model weighs about 6,000 lbs in air and replaces 6,000 lbs of seawater.

Now, that's "precisely" what I'm talking about!

The Quest 5 — owned by the University of Bremen — was deployed to a mid-Atlantic vent field. Vent fields are where super hot water comes out of the ocean floor in the spreading zones where the Earth's plates are spreading apart. Chimneys form on the sea floor in these vent fields from the precipitation of hydrogen sulfide that comes up out of the super-heated water.

The University of Bremen was going to take samples from a hole in one of these chimneys. The hole is only a centimeter in diameter. The sampling probe was only slightly smaller than that.

The probe was attached to the frame of the Quest 5. The Quest 5 pilots were able to fly the Quest 5 and — using the automatic control mode — keep the probe inside the chimney for a full hour. This was the amount of time that the scientists needed for their sampling.

All this was done 3,000 meters below the surface of the

RESOURCES

Schilling Robotics' home on the web
www.schilling.com

Odyssey Marine Exploration
www.shipwreck.net

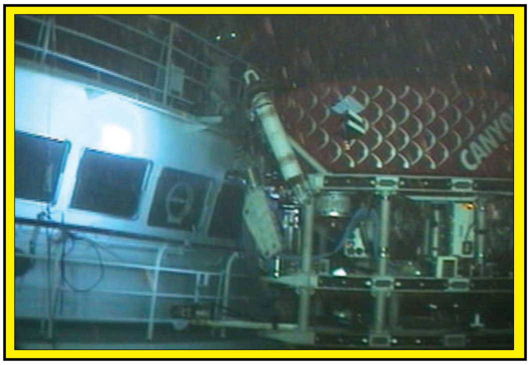
Biography of Jacques Cousteau (since he got a mention)
www.incwell.com/Biographies/Cousteau.html

The Sussex Project
http://shipwreck.net/sussex.html

The University of Bremen
www.uni-bremen.de/sitemap/sitemap_en.php3

ROVs
http://oceanexplorer.noaa.gov/technology/subs/rov/rov.html

The ROV underwater.



The ROV again, working away.

water. At the same time, the Quest 5 could not set down on the sea floor in this type of location; it maintained its position the entire time, flying with an accuracy much narrower than one centimeter.

Got an Ehemi in That Thing?

The Quest 2 was put into active duty shortly after its construction to help recover the Japanese fishing vessel, the *Ehemi Maru*. The fishing boat was submerged off the coast of Oahu. The Quest 2 was put into action around September or October of 2001.

The Quest worked a whopping 1,200+ hours of bottom time. Operations were around 2,000 ft underwater. The sea floor around the project was strewn with rigging, drilling equipment, and other machinery needed to raise the boat.

The Titan 3 Manipulator — the Biceps of the Quest and Other ROVs

The Titan 3 Manipulator arm is mostly titanium, from which it gets its name. The Titan is so durable that some of its owners have worked them 12 to 14 years only to have them checked out or rebuilt to start work again. Is it strong? A Titan 3 arm can lift 1,500 lbs underwater when curled back toward its base and 250 lbs when fully outstretched.

Building Blocks

The technology behind the Quest is unique in that it is highly modular. The "building blocks" that make up the Remote Systems Engine from which the Quest is built is a collection of hardware and software modules. These were specifically designed to let Schilling and its customers build a variety of types of remote controlled equipment for use deep in the ocean.

The Remote Systems Engine has everything you need built in — actuation, power, communications and control technologies, and other sub-systems. These enable the builder to make ROVs like the Quest series, as well as many other types of undersea equipment.

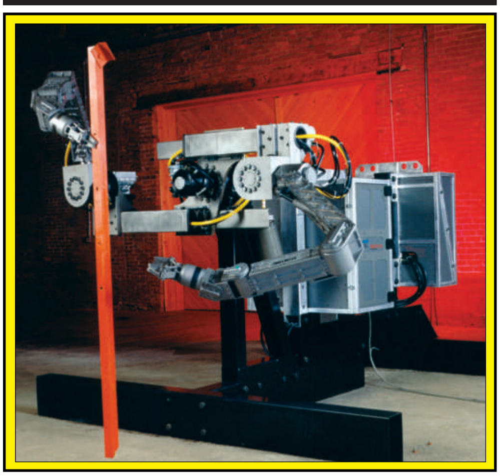
Examples of such equipment include drilling machines, one of which is being built to take 50 meter core samples out of the ocean floor at a depth of 3,000 meters. The Remote Systems Engine speeds the engineering process and makes the technology reusable.

The Birth of Thor-r-r-r-r-r-r-r-r!

In only the first year of the Robot Wars event, the Schilling Robotics team saw a flyer ad for the mechanized mayhem and decided to attend — as observers only.

They got so excited they had to build a competition robot to put in the ring the very next year. While Tyler Schilling fully funded the construction of Thor out of his own pocket, these roboticists worked together — nights

"Hey, Joe, let's take a look at this red thing here just in front of that black thing there."



"ALUMINUM, TITANIUM, AND PLASTIC, OH MY!"

The Quest Remotely Operated Vehicles (ROVs) are made of aluminum, titanium, and engineering plastics. Each material is selected based upon the specific application of the part it will form.

Choice engineering plastics are ideal where parts will be lightly to moderately stressed and exposed to erosive conditions, which the plastics are resistant to. These plastics vary slightly in their mild buoyancy, which helps bring the ROVs to proper overall buoyancy in order to displace the correct weight in water to be useful. An ROV must be weight efficient in water, just as an aircraft must be in air.

Titanium is used in parts that are heavily stressed and in situations where corrosion can cause components to fail. Aluminum is useful for moderately stressed applications and where corrosion isn't such an issue. Aluminum is also used where it wouldn't be economically feasible to fabricate the given component out of the more expensive titanium.

and weekends — to have it completed on time.

Thor was a heavy weight, which — back then — was about 185 lbs. Thor was built a little too heavy, but was trimmed down in certain places to make weight. Thor had four wheels and was about 2.5 ft wide by 4 ft long. Thor was steered by two front wheels and the power source was a go-cart engine made by Yamaha. The Yamaha engine drove an aerospace hydraulic pump.

Schilling's own Quest ROV. (Crane sold separately. [That's a joke!])

Both the drive and the operation of the titanium hammer in the middle of Thor were hydraulic. (Is it me or do these guys really, really like titanium?) Thor's hammer came down on its opponents so fast that Thor came off the ground before its hammer even struck anything. This hammer totaled many a bot part and kept the crowds roaring.

A Thor Victim

In one event, a robot team was using a Briggs & Stratton lawn mower engine on their robot. Thor damaged that engine severely. When the Schilling team went over to talk with them, the guy on the other team exclaimed how he had only bought the engine temporarily on his credit card and was planning to return it come Monday morning!

Battle Royal

That year, Thor made it to the final battle against The Master. Toward the end, Thor appeared to be winning, having disabled one of The Master's drive wheels. When Thor came in for the kill, The Master swung around and drove its spiked tail into the side of Thor.

ROV equipment above water at recovery operation.

Remember how we mentioned that Thor had to trim down to make weight? Well, the trimming was done by milling down that very area of the frame to a very fine thinness. When the spiked tail hit the outer housing of the centrifugal clutch on the go-cart engine, it stopped its output and Thor began to lose its hydraulic power. The Master had won.

Round Two

Later, Thor was invited to a rematch with The Master for a UK

Recovering another ROV.

The Master Arm Controller that you see in the picture is the device used to control the large manipulators. Essentially, the large arm (called the slave arm) mimics the position of the master arm. All an operator on the surface has to do is move the master arm around and the slave arm will follow along 10,000 feet underwater. Switches on the end of the master arm allow the operator to open/close the jaw, rotate the wrist, and "freeze" the slave arm.

Remember the BLEEX Project? Schilling Robotics has signed on to construct part of the next iteration of the BLEEX exoskeleton. Photo courtesy of UC Berkeley.

television show on robot wars. Thor traveled to London to meet The Master once more. The TV people had built a stage and were obviously going for over production with this show.

Though the match was thrilling, Thor lost again. This time, The Master's front saw cut through Thor's Kevlar shell and on through a hydraulic line. Today, Thor is retired, relaxing comfortably in a storage rack at Schilling Robotics in California. SV

THE TITAN 3 GOES ON AN "ODYSSEY"

Schilling's latest manipulator arm — the Titan 3 — has become famous. The arms are in use as part of the Odyssey Marine Exploration.

Schilling Robotics provides Titan 3 manipulator arms with integrated positioning sensors and software to Odyssey Marine Exploration and its Remotely Operated (undersea) Vehicle (ROV), which has been working on the noted *HMS Sussex* Project.

The *Sussex* is a British war vessel that was lost at sea around 1694 off the Straits of Gibraltar during an intense storm. The *Sussex* is believed to have been carrying a large hold of money at the time. Believing they have located the very ship, the UK and the Odyssey team are excavating it.

The Titan 3 arms will enable Odyssey archaeologists to much more easily and quickly track and record the exact position of *HMS Sussex* artifacts as they are being collected.

The Titan 3 arms have seven different functions that allow for precise, fine work such as is necessary in undersea archaeological work. No previous manipulator arm has been capable of the Titan 3's new three-dimensional positioning feedback of the X, Y, and Z axis reporting.

The *Sussex* project is 3,000 feet below the surface. The work is highly intricate and the Titan 3 arms may just make it possible to successfully recover more artifacts safely — and do it more quickly, as well.

Robytes

by Dave Calkins

Another month, another collection of robot trivia to amuse your coworkers and annoy your pub-mates. Surely there are more fun stories out there. Got a good story on robots? Email me: news@robotics-society.org If you'd like to get even more robot news delivered to your in-box (no spam, just robo-news) drop a line: subscribe@robotics-society.org

— David Calkins

Prophets, Beware! Robots Now Walk on Water

Photo courtesy of Carnegie-Mellon.

Robots can finally do what Jimmy Swaggart has longed to do since he started talking credit card donations — walk on water. Metin Sitti — in charge of Carnegie-Mellon's NanoRobotics Lab — has devised a way to make lightweight robots that don't float like boats, but walk on water, like stick bugs and water spiders. (It's time to dig out those notes from your freshman physics class on "surface tension.")

Each bot is only half an inch on average, but moves at about a meter a second. That's faster than your best Olympic swimmers (who are still human, as of this writing ...). Just like a water spider, it skims the surface of the water on eight legs — without sinking or resorting to buoyancy devices. The body is super light carbon fiber and the legs are wires with water-repelling plastic. The bugs move in an almost surfer-like fashion — pushing the water back enough to start ripples, but not enough to break the surface tension. The robot can also just "stand" on the water.

Right now, the bots don't have any brains, cameras, or transceivers — just simple actuators to make them move — but the upgraded features can't be far behind. So, when the robots take over, we'll see them coming from both the hills and the ocean.

One, if by land; two, if by sea?

Breaking Up Is So Easy to Do

Photo courtesy of Dartmouth.

A team led by Zack Butler of New Hampshire's Dartmouth College has developed new programs for robots that can break apart and join back together. Think of ants in the Amazon — they move an S-shaped column, but then walk over each other to build a bridge across a stream.

Each robot module is part of a greater whole, but they can all act independently. One module can break apart from the main group and explore a new area or individually go over an obstacle in the path of the massed robot, later to re-join the robot.

Because of the way modules attach to each other, the bot should change shape (to go snake-like under an opening or biped-like over a big object). Of course, if they're overrunning the last bastion of humanity and you shoot one, they can just break up and re-join the remaining parts. On the brighter side, they'd also be very good at exploring planets — instead of sending one rover, you could send one of these bots to cover much more ground.

I bet they'd also be great at picking up all my dirty socks.

Rosie the Robot Finally Arrives!

Photo courtesy of Fujitsu.

You've wanted it — you know you've wanted it. It's finally here! The robot maid. Fujitsu has developed a service robot that can act pretty much as a butler or concierge for all of you well-heeled bot enthusiasts. The robot is hyped as being able to greet and escort guests onto elevators, operate the elevators, move a mail cart, and act as a security guard — among other features.

You may remember Fujisoft as the developer of HOAP — the robot featured here a few months ago that does Tai-Chi (pre-RoboOne). That robot comes complete with a 3-D visual processing system to detect objects, just like a real person. It can move through an office (or home) while quickly perceiving people or things in its surrounding

areas and simultaneously measuring their locations through the use of two of its eight cameras.

The system is refined sufficiently to let it walk next to people — keeping up with them without bumping into them. The arms can autonomously grab objects, move them, and even hand things to people. Like the best of butlers, it can detect where your voice is coming from and follow instructions. It even knows when it's running low on power and can charge itself.

It sounds perfect for cleaning up the non-essential parts of the house — meaning everything but the garage workshop — just as long as it doesn't steal the silverware.

Cyberdyne and Skynet, Here We Come ...

For the first time in history, a robot has built its own synthetic central nervous system and learned how to not only walk, but autonomously enter and navigate the corridors of complex buildings. Dr. Stephen Thaler of Imagination Engines, Inc. (IEI), in St. Louis, MO, has built a robot that learns on its own.

Most autonomous robots aren't truly autonomous — they have simple programs that rarely actually store information and almost never actually learn. "Immense scholarly efforts have been poured into writing 'if-then-else' computer programs," he says, but — with these new neural networks — Thaler and his assistants simply sit back, fold their arms, and watch neural networks spontaneously connect themselves into the neural circuitry required for extremely ambitious robotic brains in a matter of seconds.

The resulting neural network architecture both resembles and functions like a brain. It's a collection of individual neural networks fused into a contemplative system that can form complete models of their worlds, consider alternative scenarios, and finally choose that alternative best suited to a given problem.

"The neural circuitry developed through genetic programming is only 'reactive.' They are tantamount to reflex reactions in the brain or spinal chord, wherein a stimulus simply triggers a response. The self-forming brains of IEI's robots are entirely different. Like human brains, they think, experiment, and automatically perfect their behaviors to produce downright unexpected results — what can only be called creativity," says Thaler. (Are you getting this, Miles Dyson?)

Recently — in a dramatic experiment conducted for the DoD (Department of Defense) — IEI scientists and engineers built a complex hexapod robot that effectively began life as a kind of "cybernetic road kill" — essentially a heap of tangled legs and electronics that learned how to walk in a period of only minutes.

Continuing its learning in virtual reality, it self-originated new methodologies for navigating complex facilities and landscapes, as well as novel kinds of locomotion, wherein it assumed bipedal stances to quickly evade threats. Awakened from its virtual reality test environment, it could then carry out similar behaviors in reality.

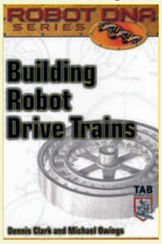
The military is likewise considering such creative robots as sensor platforms for force protection and urban warfare scenarios. Visionary military thinkers see these robots fulfilling roles ranging from that of brilliant swarm munitions to the fully autonomous neural network-based cyber-warriors anticipated by science fiction.

Really — after California elected you-know-who — should we be surprised? SV

Mind Candy For Today's Roboticist

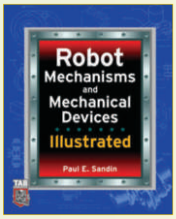
The *SERVO* Bookstore

Building Robot Drive Trains
by Dennis Clark / Michael Owings



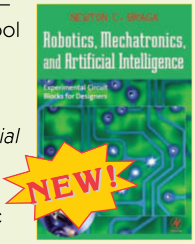
This essential title in McGraw-Hill's *Robot DNA Series* is just what robotics hobbyists need to build an effective drive train using inexpensive, off-the-shelf parts. Leaving heavy-duty "tech speak" behind, the authors focus on the actual concepts and applications necessary to build — and understand — these critical, force-conveying systems. **$24.95**

Robot Mechanisms and Mechanical Devices Illustrated
by Paul Sandin



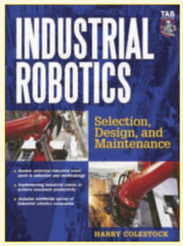
Both hobbyists and professionals will treasure this unique and distinctive sourcebook — the most thorough — and thoroughly explained — compendium of robot mechanisms and devices ever assembled. Written and illustrated specifically for people fascinated with mobile robots, *Robot Mechanisms and Mechanical Devices Illustrated* offers a one-stop source of everything needed for the mechanical design of state-of-the-art mobile 'bots. **$39.95**

Robotics, Mechatronics, and Artificial Intelligence
by Newton C. Braga



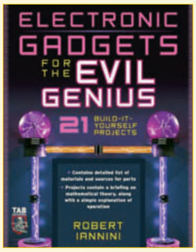
Accessible to all readers — including secondary school students and amateur technology enthusiasts — *Robotics, Mechatronics, and Artificial Intelligence* simplifies the process of finding basic circuits to perform simple tasks — such as how to control a DC or step motor — and provides instruction on creating moving robotic parts, such as an "eye" or an "ear." Though many companies offer kits for project construction, most experimenters want to design and build their own robots and other creatures specific to their needs and goals. With this new book, hobbyists and experimenters around the world will be able to decide what skills they want to feature in a project and then choose the right "building blocks" to create the ideal results. **$31.95**

Industrial Robotics
by Harry Colestock



With so many industries taking advantage of the tremendous advances in robotics, entities ranging from small family businesses to large corporations need assistance in the selection, design, set-up, maintenance, and economic considerations of industrial automation. *Industrial Robots* shows how to achieve maximum productivity with robotics, classifies robots according to their complexity and function, and explains how to avoid common automation mistakes. **$39.95**

Electronic Gadgets for the Evil Genius
by Robert Iannini



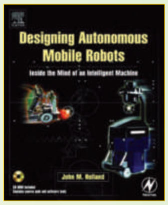
The do-it-yourself hobbyist market — particularly in the area of electronics — is hotter than ever. This book gives the "evil genius" loads of projects to delve into, from an ultrasonic microphone to a body heat detector, all the way to a *Star Wars* Light Saber. This book makes creating these devices fun, inexpensive, and easy. **$24.95**

Robot Builder's Sourcebook
by Gordon McComb

Fascinated by the world of robotics, but don't know how to tap into the incredible amount of information available on the subject? Clueless as to locating specific information on robotics? Want the names, addresses, phone numbers, and websites of companies that can supply the exact part, plan, kit, building material, programming language, operating system, computer system, or publication you've been searching for? Turn to the *Robot Builder's Sourcebook* — a unique clearinghouse of information that will open 2,500+ new doors and spark almost as many new ideas. **$24.95**

We accept VISA, MC, AMEX, and DISCOVER
Prices do not include shipping and may be subject to change.

Designing Autonomous Mobile Robots
by John Holland



Designing Autonomous Mobile Robots introduces the reader to the fundamental concepts of this complex field. The author addresses all the pertinent topics of the electronic hardware and software of mobile robot design, with particular emphasis on the more difficult problems of control, navigation, and sensor interfacing. Its state-of-the-art treatment of core concepts in mobile robotics helps and challenges readers to explore new avenues in this exciting field. The accompanying CD-ROM provides software routines for the examples cited, as well as an electronic version of the text. **$49.95**

PIC Robotics: A Beginner's Guide to Robotics Projects Using the PIC Micro
by John Iovine

Here's everything the robotics hobbyist needs to harness the power of the PICMicro MCU! In this heavily-illustrated resource, the author provides plans and complete parts lists for 11 easy-to-build robots — each with a PICMicro brain. The expertly written coverage of the PIC Basic Computer makes programming a snap — and lots of fun. **$19.95**

Mobile Robotic Car Design
by Pushkin Kachroo / Patricia Mellodge

This thoughtful guide gives you complete, illustrated plans and instructions for building a 1:10 scale car robot that would cost thousands of dollars if bought off-the-shelf. But, beyond hours of entertainment and satisfaction spent creating and operating an impressive and fun project, *Mobile Robotic Car Design* provides serious insight into the science and art of robotics. Written by robotics experts, this book gives you a solid background in electrical and mechanical theory, and the design savvy to conceptualize, enlarge, and build robotics projects of your own. **$29.95**

To order call 1-800-783-4624 or go to our website at www.servomagazine.com

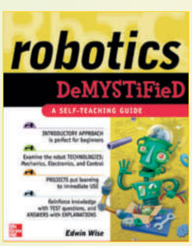
PIC Microcontroller Project Book
by John Iovine

The PIC microcontroller is enormously popular both in the US and abroad. The first edition of this book was a tremendous success because of that. However, in the four years that have passed since the book was first published, the electronics hobbyist market has become more sophisticated. Many users of the PIC are now comfortable paying the $250.00 price for the Professional version of the PIC Basic (the regular version sells for $100.00). This new edition is fully updated and revised to include detailed directions on using both versions of the microcontroller, with no-nonsense recommendations on which one serves better in different situations. **$29.95**

Robot Builder's Bonanza
by Gordon McComb

Robot Builder's Bonanza is a major revision of the bestselling bible of amateur robot building — packed with the latest in servo motor technology, microcontrolled robots, remote control, LEGO Mindstorms Kits, and other commercial kits. It gives electronics hobbyists fully illustrated plans for 11 complete robots, as well as all-new coverage of Robotix-based robots, LEGO Technic-based robots, Functionoids with LEGO Mindstorms, and location and motorized systems with servo motors. **$24.95**

Robotics Demystified
by Edwin Wise

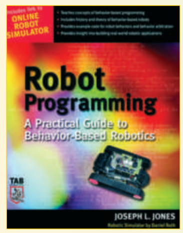


There's no easier, faster, or more practical way to learn the really tough subjects. McGraw-Hill's *Demystified* titles are the most efficient, intriguingly written brush-ups you can find. Organized as self-teaching guides, they come complete with key points, background information, questions for each chapter, and even final exams. You'll be able to learn more in less time, evaluate your strengths and weaknesses, and reinforce your knowledge and confidence. **$19.95**

Build Your Own Humanoid Robots
by Karl Williams

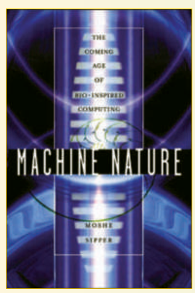
Build Your Own Humanoid Robots provides step-by-step directions for six exciting projects — each costing less than $300.00. Together, they form the essential ingredients for making your own humanoid robot. **$24.95**

Robot Programming
by Joe Jones / Daniel Roth



Using an intuitive method, *Robot Programming* deconstructs robot control into simple and distinct behaviors that are easy to program and debug for inexpensive microcontrollers with little memory. Once you've mastered programming your online bot, you can easily adapt your programs for use in physical robots. **$29.95**

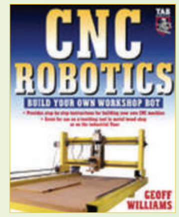
Machine Nature: The Coming Age of Bio-Inspired Computing
by Moshe Sipper



Despite being marvels of complexity and human ingenuity, computers are notoriously bad at learning new things and dealing with new situations. Researchers at the frontiers of computer science have turned to nature for solutions to the problem of machine adaptation and learning. By applying models of complex biological systems to the realm of computing machines, they have given rise to a new breed of adaptive software and hardware. In *Machine Nature*, computer scientist Moshe Sipper takes readers on a thrilling journey to the terra nova of computing to provide a compelling look at cutting-edge computers, robots, and machines now and in the decades ahead. **$24.95**

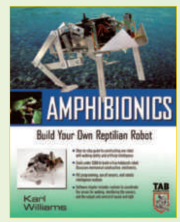
Check out our online bookstore at www.servomagazine.com for a complete listing of all the books that are available.

CNC Robotics
by Geoff Williams



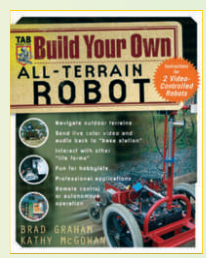
Now, for the first time, you can get complete directions for building a CNC workshop bot for a total cost of around $1,500.00. *CNC Robotics* gives you step-by-step, illustrated directions for designing, constructing, and testing a fully functional CNC robot that saves you 80 percent of the price of an off-the-shelf bot and can be customized to suit your purposes exactly, because you designed it. **$34.95**

Amphibionics
by Karl Williams



If you're a robotics hobbyist with a flair for creativity, here's your opportunity to join the revolution and advance robotic evolution. This work provides the hobbyist with the detailed mechanical, electronic, and PIC microcontroller knowledge needed to build and program snake, frog, turtle, and alligator robots. It focuses on the construction of each robot in detail and then explores the world of slithering, jumping, swimming, and walking robots — and the artificial intelligence needed with these platforms. Packed with insight and a wealth of informative illustrations, *Amphibionics* focuses on construction details and explores the artificial intelligence needed to make these specialized movements happen. **$19.95**

Build Your Own All-Terrain Robot
by Brad Graham / Kathy McGowan



Remotely operated robots are becoming increasingly popular because they allow the operators to explore areas that may not normally be easily accessible. The use of video-controlled technology has sparked a growing public interest not only in hobbyists, but also in the areas of research, space, archeology, deep sea exploration, and even the military. Inside *Build Your Own All-Terrain Robot*, the writers enable even total newcomers to robots to construct a rugged, video-controlled, talking, seeing, interacting explorer bot with a range of over a mile for under $200.00! **$29.95**

BEAM Robotics Step by Step PART 3

Chains, Cores, and Wallbanging

by Thomas Gray and J. Wolfgang Goerlich

Patterns are the rhythms that set the beat of our lives. Walking is a pattern: step, shift, step, shift, and away you go. Chewing is a pattern, too. So is tapping your foot to the beat of music or any dancing that you can think of. The best part is that patterns seem so natural; you just do them. There's no need to think about it; just move.

These patterns originate in our Central Nervous System (CNS), apparently in bundles of neurons that wire into our muscles. When the need to move comes, these bundles start firing in an organized pattern. Practically all animals have these Central Pattern Generators (CPGs) governing their locomotion. Then, higher level "thinking" areas send signals to the CPGs to start, stop, or influence the pattern.

In this article, we will use Nervous Net technology to mimic CPGs. Then, we'll show you how to trick a CPG into wall following and simple maze solving.

Need More Input

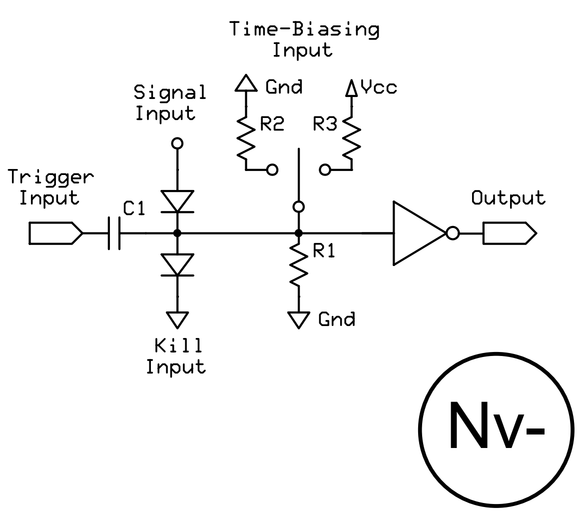
Figure 1 illustrates the Nv Neuron with a few new inputs. You should already be familiar with the *Trigger Input*; this is the standard input from the last article. A signal comes in on the input, triggering the Nv. The Nv turns on and stays active for several seconds. The product of R1 and C1 determines this active period, often called a process. Time in seconds equals resistance in megohms, multiplied by capacitance in microfarads.

The *Signal Input* acts like the Trigger Input; it starts new processes when set to Vcc. Unlike the Trigger, Signal Input will hold the Nv active indefinitely. The RC time-out starts after the Signal Input is turned off or set to GND.

The *Kill Input* sounds ominous, but it is useful. When connected to GND, the Kill Input bypasses the resistor (R1) and almost instantly drains the capacitor (C1). If the Kill Input is low before the process comes in, then the process simply does not start. The Nv does not pass it on to any other Neurons or circuitry. If the Kill Input goes low while the Nv is active, this truncates the process. So, a low (GND) signal to the Kill Input will either prevent or shorten the process.

Lastly, *Time Biasing Inputs* change the RC time-out. When connected to ground, a resistor — such as R2 — decreases the total resistance. When connected to Vcc, the two resistors — R1 and R3 — form a voltage divider, which can either lengthen the process or create new processes, depending on the ratio between the two resistors.

Figure 1. Nv "nervous" neuron.



Connect the Dots

One Nv does not a Net make. We need to connect them somehow. Let's start by wiring one Nv's output into another's Trigger Input. The total process time-out is the sum of the neurons' time-outs (Figure 2).

With a string of three Nvs, the resulting Net looks like a chain with each neuron forming a link (Figure 3). Because of that, we call this topology a

Figure 3. A chain of Nv neurons.

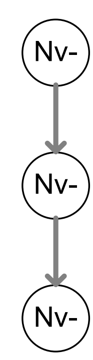
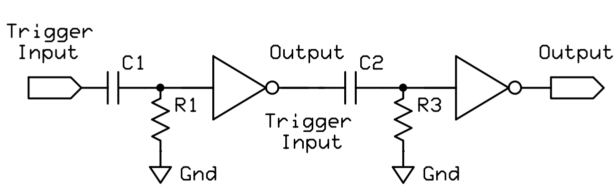


Figure 2. Two connected Nvs.



chain. When the first Nv in the chain receives a process, it then passes the process to the next Nv, which passes it on down the chain. Sort of a neuron pass-the-process relay race. (Yes, this was written during the Olympics.)

In the last article, we saw how a single Nv can be made to fire in response to light. Now, we can see how the processes from a single Nv can be fed into an entire chain of Nvs. The output of each Nv provides the trigger for the next, but each output can be used to control something else. The result is a sequence of events with variable timing. A process fires off and runs until the end of the chain, where it falls off.

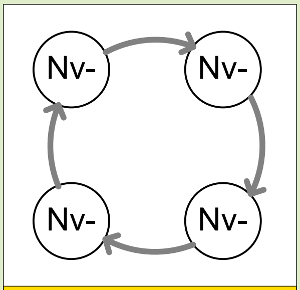


Figure 4. A four-Nv loop or quadcore.

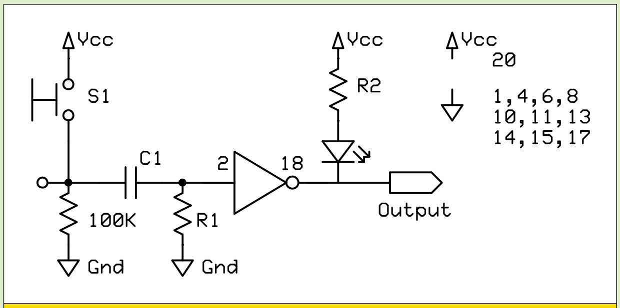


Figure 5. Nv with indicator and PIC.

What if we want to keep the process running? Well, picture the Nv chain as a string. By tying the string together in a loop, a process started at any Nv will continue around the chain. Connect the last Nv's output back to the first Nv's input. Looped Nervous Nets are said to be in a core topology.

Wow, we are learning a lot! Now, we can say, "My CPG uses four Nvs in a core topology, branching into three Nvs in a chain topology." Whew, that's a lot to write, let alone to say.

In a shorthand notation, we use the numeric prefix (bi-, quad-, etc.) to mark how many neurons are in a Nervous Net. Then, we state the topology in the root. So, for chains of Nvs, we write Bichain, Trichain, or Quadchain for links of two, three, or four. The same goes for cores, where we have Bicores, Tricores, and Quadcores.

Step 1: Playing With Chains

Pull out your breadboard. Take a 74AC240 or 74HC240. Choose the resistor and capacitor values at random, providing that you have four matched pairs. You'll want the time-out to be long enough to be observable without being so long as to be unbearable. Caps around 0.1 µF or 0.22 µF and resistors in the 1M to 5M range work well.

Plug in the '240 and run the ground lines to pins 1, 10, and 19. Put the first Nv — Nv (2, 18) — on the breadboard along with the PIC, as shown in Figure 6. Ground the remaining inputs. Add power and test with a PIC switch (Figure 5). The neuron should go active and then time-out.

Remove the ground from pin 4 and build Nv (4, 16). Place Nv (4, 16)'s capacitor across the channel. Plug it into pin 4 and Nv (2, 18)'s output. When you trigger the PIC, Nv (2, 18) becomes active. It times out and passes the process to Nv (4, 16). Wait, and Nv (4, 16) times out.

Add the next two Nvs so that the first bank is populated. After each Nv, test the performance of the chain.

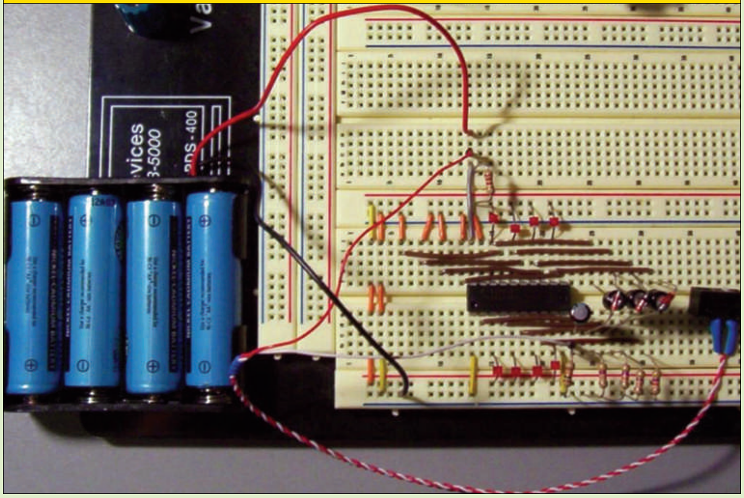
By the time you reach a Quadchain, you'll notice that something just isn't right. Nv (2, 18) will always work properly. Nv (4, 16) should be all right. The other two neurons, though, will act a little strange. Why?

Let's trace it out. The action of the PIC provides Nv (2, 18) with a clean transition from active to inactive. Because Nv (2, 18) switches cleanly, Nv (4, 16) also receives a fairly clear signal. However, Nv (4, 16)'s output will not be as clean. The farther away from the clear low signal of the

WILF RIGTER AND THE CASE OF THE TWITCHY QUADCHAIN

Credit for the solution goes to Wilf Rigter, a regular contributor on the BEAM group at **http://groups.yahoo.com/group/beam/**

Figure 6. Quadchain on the breadboard.



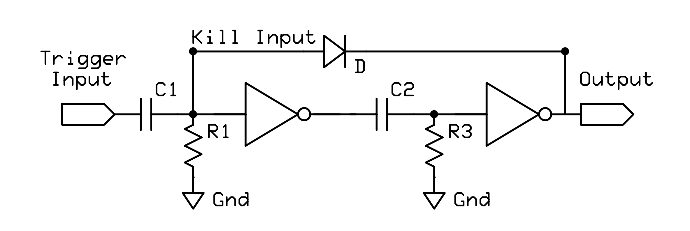


Figure 7. Two dual-connected Nvs.

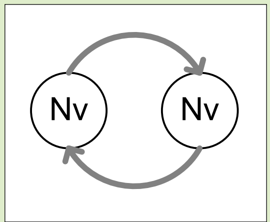


Figure 8. A two-Nv loop or bicore.

THE HISTORY OF WALLBANGING

Why is this robot called Harvey Wallbanger? After the vodka and OJ cocktail? Well, its gait might remind you bit of someone who's had a few ...

The original Harvey Wallbanger competed in the IEEE Micro Mouse contest during the 1980s. It could be switched to use either the left-hand or the right-hand rule for maze solving. It won prizes for both the fastest time and the most improved. Tom developed the BEAM Bicore version presented here, but it's entirely possible that someone else thought of it first. If so, we apologize for not giving due credit.

PIC's pull-down resistor, the more noise there is.

As we know, the '240 switches at half of Vcc. If a signal on an inverter's input is close to the switching point, the inverter will switch rapidly high and low. Earlier, this was useful in building robots like the Bare Bones Photovore.

Now, however, this is problematic because the next Nv might twitch a bit when its input switches. If it twitches even a little bit, then the next Nv in the chain will also switch on and off rapidly.

Before you know it, all Nvs on the chain start bouncing on and off and you get a light show. That might be fun, but it's not what you want.

The problem of the twitchy Quadchain can be simplified to one Nv in a chain not becoming inactive when the next becomes active. We can solve this problem by connecting the Nvs using the Trigger input and the Kill input (Figure 7).

The first Nv becomes active, then passes the process to the second Nv. The moment the second Nv switches, it sends a kill input back to the first Nv. Thus, the chain cleanly switches and the process smoothly circulates from one Nv to

the next.

Remove Nv (8, 12) and ground its input. Add the kill input diodes to the remaining Nvs. By repeatedly pressing the PIC switch, see how many processes you can squeeze into the Trichain.

Once you have the Trichain down, add Nv (8, 12) back into the mix. Remember to use both the Trigger (capacitor across the channel) and Kill (diode) connections. See how many processes you can get running in a Quadchain.

Did you catch the pattern? Cram in as many processes as you can and the pattern becomes 1010 or 0101. Two successive Nvs will not be active simultaneously. Thus, the maximum number of processes is the number of Nvs divided by two (n/2).

You can consider this the "saturation point" of the Net. When you hear a BEAMer complaining of a saturated Hexcore, you know that it has three processes running on alternating Nvs in a loop.It's now time to play around a bit. How about a BEAM stoplight? If you have three different colored LEDs, set up a traffic light pattern and play with the timing in a Trichain. Could be fun for a model railroad. Once you have that down, try the Tricore.

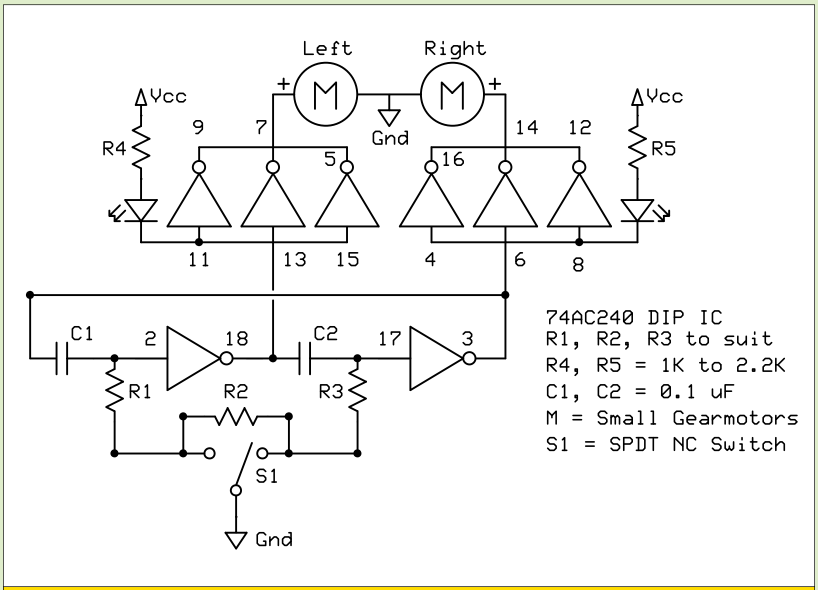


Figure 9. Harvey Wallbanger schematic.

Step 2: Building With Cores

This project — Harvey Wallbanger — uses an unbalanced Bicore as its tiny brain — just barely enough intelligence to follow a wall! Time-Biasing inputs (refer back to Figure 1) are used to steer the bot and a single tactile sensor is used to locate the wall.

A Bicore is, obviously, the simplest Nv core possible: two Nv neurons in a loop.

Now, take a look at Figure 9 — the schematic for Harvey Wallbanger. The Bicore is shown at the bottom, with the remaining inverters ganged as motor drivers. In operation, each Nv is active for a period of time specified by C1 and its resistor(s). During this time, the process outputs to a motor, causing the bot to turn in a short arc. The bot will waggle left, then right, etc. If R2 and S1 were not present and the junction of R1 and R3 were connected to ground, the Bicore would be balanced and the bot would go fairly straight.

Because the resistances at each Nv are unequal (depending on the position of switch S1), one half of the Bicore will

HEY, I COULD DO THIS WITH A ...

You might look at this month's project and think, "Hey, I could do that with a 555 chip, or a PIC, or a handful of transistors, or whatever." True, all true — there are many ways to make astable (two state) oscillators. This series of articles is focusing strictly on the classic RC circuits used to make BEAM Nervous Nets. If you are more adept at one of the other circuits or ICs, then — by all means — make your own Wallbanger and let us know how it turns out.

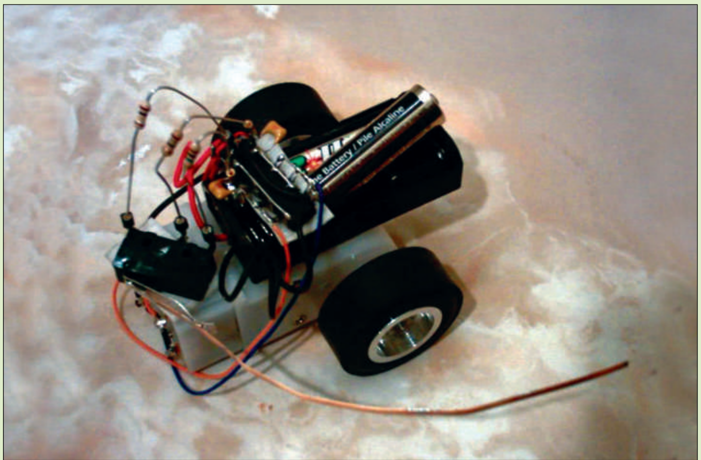


Figure 10. Harvey Wallbanger photograph.

always have a longer process than the other, and the bot will tend to turn. Rig your motors so that the normal — S1 closed — turn is to the left, which for Harvey is towards a wall. (Harvey is a liberal, left-leaning wallbanger. If you prefer a conservative, right-leaning wallbanger, just reverse the switch!)

When the feeler on S1 hits a wall, the switch opens and R2 is associated with the opposite half of the Bicore, causing that half to be on longer. This results in a turn to the right, away from the wall.

Once Harvey has turned away enough for the feeler to lose contact with the wall, S1 will close and Harvey will head back toward the wall. If you don't get this behavior, swap your motor and switch leads around until everything works right.

We'll leave the mechanics to you. You can use the gearmotors from TimerBot (as explained the September, 2004 issue of *SERVO*) or turn up new ones if you don't want to sabotage your existing robot. In our prototype, the SPDT switch was salvaged from an old computer mouse with a length of springy brass strip epoxied to the switch tab. Be creative!

In the photo of our prototype of Harvey, you'll notice little sockets soldered to the switch pins and to parts of the "free-formed" circuit. This is so various resistors could be tried "on the fly" to change how much the bot would turn. The switch is fastened to the motor cases with double-sided foam tape. Be prepared to do some experimenting to find the best angle and length of feeler to get the best results.

One use for Harvey's pattern of movement is maze solving. A popular method for solving a maze is the left-hand rule. Keeping your left hand on the wall and following it around will eventually get you out.

This only works for mazes that have all of the walls connected together, though, but it is a good strategy nonetheless.

So, the next time you find yourself stuck in a labyrinth with friends, family, or a Minotaur, think of *SERVO Magazine*.

Quickly build a Harvey Wallbanger, follow him out to safety, and be the hero. **SV**

PARTS LIST — For the Series

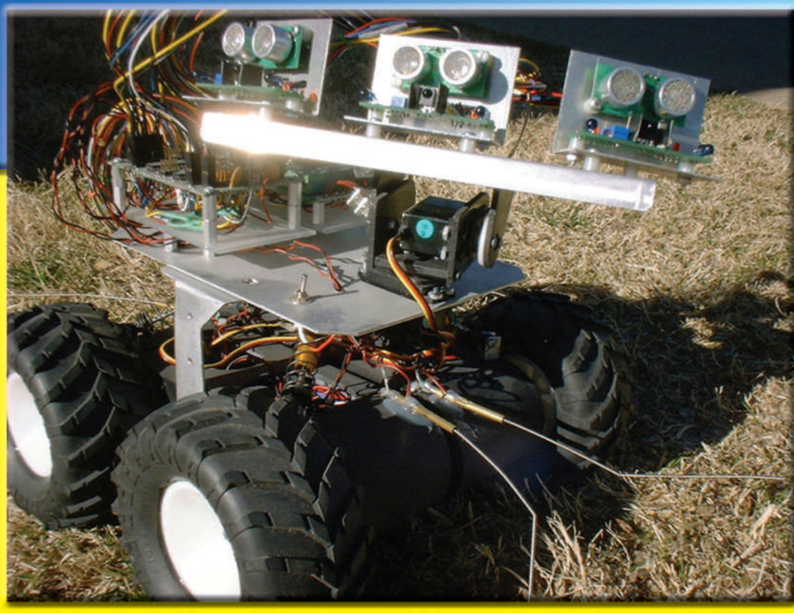
Electronics		
74AC240*	Texas Instruments SN74AC240N	Mouser 595-SN74AC240N
		Fairchild MM74AC240N
		Solarbotics 74AC240
Photodiodes	Siemens SFH205f Wide Field	Solarbotics IR1
	Salvaged from computer mouse	—
Asst. LEDs*	Tiny Red LEDs	Mouser 638-204HD
	Tiny Green LEDs	Mouser 638-204GT
	Tiny Red, Green, or Yellow LEDs	Solarbotics TLED
Resistors	Assorted, a few 470 Ω - 1K *	
	And a few in the 1M – 10M range*	
Capacitors	Assorted, 0.1 µF to 0.22 µF range*	
Mechanics		
Motors*	Two matched hobby gear motors with wheels	Solarbotics GM3PW
	Two recycled matched 'pancake' motors	
5 V Power	4 AAA or 4 AA Battery Pack*	
Power Switch	SPDT n/c lever Switch*	Solarbotics SWT9
Misc.		
Breadboard*	Generic Solderless Breadboard and Ties	

* Required for this month's projects

ABOUT THE AUTHORS

Tom works in the Research & Development department of a company that manufactures hot tubs in Alberta, Canada. Wolfgang works in IT and specializes in thin-computing solutions in Michigan, US. Hobbyists with no formal technical or electronics training, the two connected online at ***http://groups.yahoo.com/group/beam/*** *and have never met face to face.*

Center Articulated Chassis



by Curtis Ray Welborn

Have you ever wanted to take your robot off-road, but find that your current design cannot get off the driveway and onto the grass? If your wheels fail to turn when you hit rough terrain, then your motors are under-powered. If, on the other hand, your wheels are spinning, but your robot is not moving, then you have a traction problem and what you may need is some suspension. By providing a simple form of suspension, a vehicle with a center articulated chassis offers better mobility over rough terrain than a ridged chassis vehicle.

A center articulated chassis vehicle can either be purchased from such vendors as Lynxmotion, Inc. (**www.lynxmotion.com**), or they can be made from scratch. As mentioned before, a basic starting point for building a center articulated chassis is a four-wheel drive vehicle. The simplest four-wheel drive vehicle to make is a skid steer vehicle. Simply put, this means that each of the four wheels has its own motor.

While there are four motors that are needed, only two motor controllers are necessary: one for each side of the

Center Articulated Chassis Basics

The basic idea of a center articulated chassis is to divide the chassis of a four-wheel drive vehicle down the center, yielding a left and right half. Then a fifth axle is added to the vehicle, going through the center of each chassis and connecting both chassis halves together, as seen in Figure 1.

The fifth — or center — axle allows each half of the vehicle to pivot about the center axis. The new, center articulated chassis can now climb over obstacles much better than the original ridged chassis because the center axle allows the wheels to stay in contact with the ground, providing better traction to the vehicle.In this way, the center axle works like a suspension system for the vehicle.

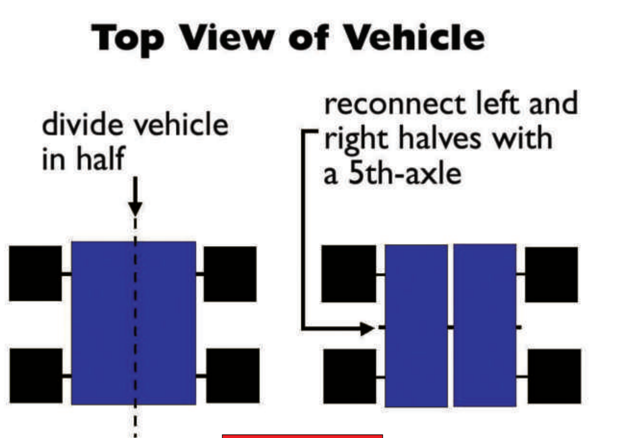


FIGURE 1

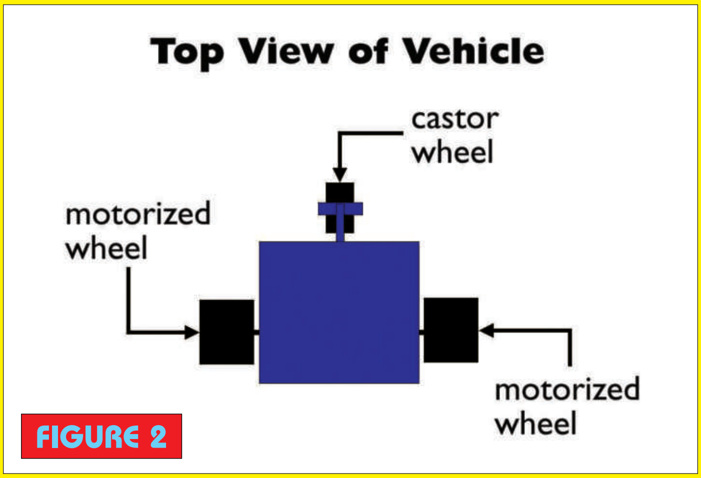


FIGURE 2

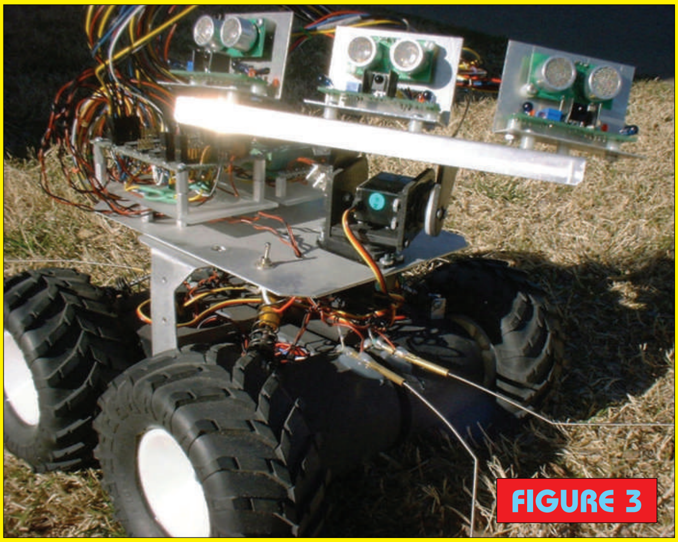


FIGURE 3

vehicle. The vehicle only requires two motor controllers because each half of the vehicle should be controlled as one single unit.

Think of the wheels of your four-wheel drive vehicle working like the tracks of a tank in that all the wheels on one side work together at all times.

To go straight, all four motors are driven at the same speed and in the same direction. To create a slow, arching turn, both motors on one side of the robot are run faster than the motors on the other side. To cause the robot to spin, just run the motors on one side forward and the others in reverse.

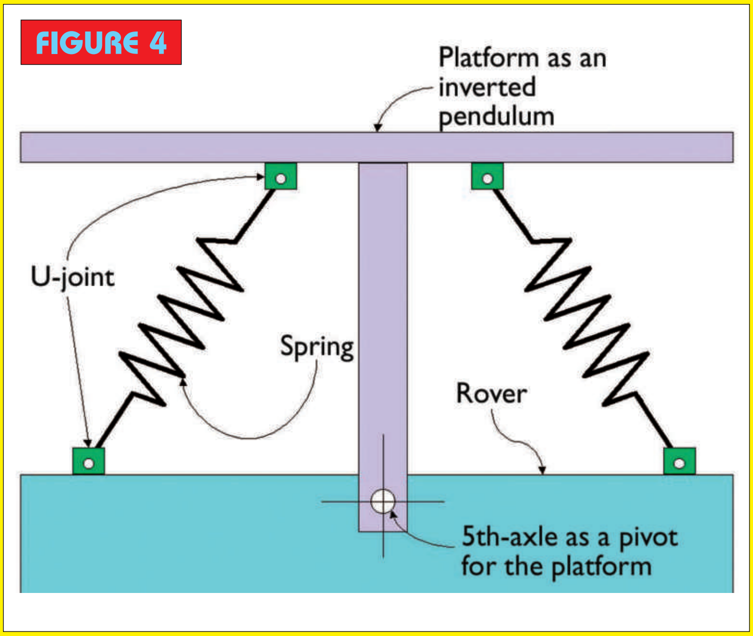
Skid steer vehicles get their name from the fact that the wheels have to slide or skid when the vehicle turns. This skidding means that more power is needed to turn the vehicle than if a simple differential drive system (see Figure 2) were used with an additional caster wheel for balance.

The additional power needed to turn a skid steer vehicle is the major drawback to this type of design. Once you understand the basic concept, you can build vehicles that use more than a four-wheel drive or even tracks, though more wheels mean more friction when turning.

Mounting Problems

The Four-Wheel Drive Rover 2 Robot Kit from Lynxmotion, Inc., was used as the base for my robot. The Rover uses four motors with a 50:1 gear reduction connected to a Dual H-Bridge Motor Controller. While the Four-Wheel Drive Rover 2 Robot Kit was a nice starting point for this robot, the disadvantage of using a vehicle with a center articulated chassis became apparent when I started attaching electronics.

The initial set of sensors consisted of three sonar sensors, three infrared (IR) sensors, and four whisker sensors. A sensor array was devised that used the three

FIGURE 4


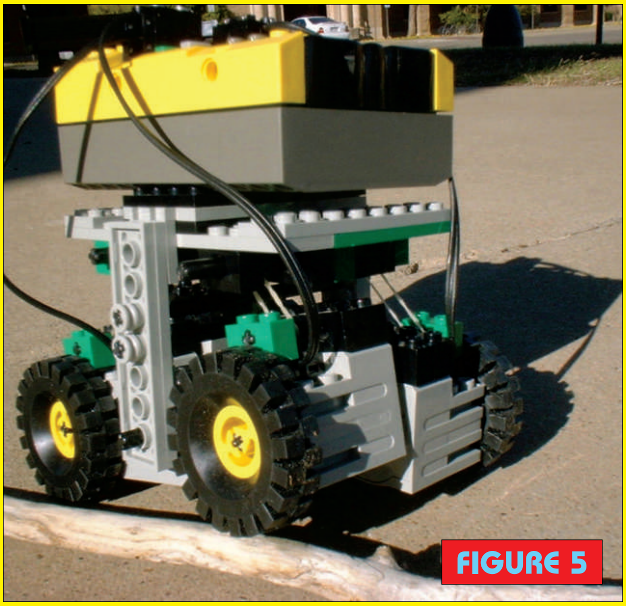


FIGURE 5

sonar and three IR sensors together. The sensor array allowed for overlapping sensor coverage while still providing a large viewing angle.

Rather than utilize a fixed-mounting point for our sensor array, it was decided that a pan/tilt kit would be used to mount the sensor array.

The pan/tilt unit (as shown in Figure 3) allowed fewer total sensors to be used while still providing about 250° coverage when coupled with the detection cone of the Ultrasonic units. The pan/tilt unit allowed the robot to focus all of its sensors in a particular direction without altering the robot's overall direction.

The pan/tilt unit needed to be placed in the center, at the front end of the robot. Placing the pan/tilt unit at the extreme front end of the robot allows the sensor array to see the ground directly in front of the robot, just past the wheels.

This configuration was desired to allow the robot to search for rapid drop-offs, such as a stairwell. Additionally, if the sensor array was not centered, the coverage the array would have provided would have been different from the left side to the right side of the robot, making navigation more difficult.

Mounting Solution

To address the problem of mounting electronics, a raised platform was developed to accept the pan/tilt unit. The platform needed to allow the chassis to continue to rotate — albeit to a much more limited degree — while maintaining a stable base from which sensor readings could be made.

The drawing of the platform (Figure 4) shows that it works like an inverted pendulum with two springs used on each side to keep the pendulum upright.

The platform provided a very stable base for the pan/tilt unit — even over rough terrain. The platform can pivot at the fifth-axle while the springs (shocks) act to limit the rotation of the rover around it. An added advantage of this configuration is that the platform will remain relatively stable, compared to the rotation of the Rover over rough terrain.

The platform was built using thin sheet aluminum, the springs are radio controlled vehicle oil damping shocks, and the U-joints were hand milled from 1/2 inch aluminum stock. If you do not have access to a milling machine, the U-joints can also be bent out of heavy sheet aluminum using pliers and lots of care. The platform provided enough surface area for a JStamp microprocessor and a multiplexer that increased the number of sensors the JStamp could interface with to be mounted directly onto it.

Simple Demo

To illustrate that complex materials are not needed for a center articulated chassis, Figure 5 shows a vehicle that was built using LEGO Mindstorm components. The design is very simple and straightforward. Each of the four wheels is directly connected to a motor. The motors on each side of the vehicle are connected together to form half of the chassis. The platform to hold the LEGO RCX was constructed from LEGO plates.

The only non-LEGO parts are the four rubberbands used in place of springs. While the little robot has only 1/4 inch of ground clearance and is very top heavy, it is able to climb over obstacles as high as 1-1/4 inches. This simple — yet unstable — design is only a starting point for building more robust vehicles.

So, if you want your next robot to get a little rough, give it a little suspension with a center articulated chassis. SV

About the Author

Curtis Ray Welborn worked at Johnson Space Center and in the telecommunications industry before returning to school at Texas Tech University to pursue his interest in robotics and a Ph.D. in Computer Science.

NETWORKS of NEURONS A Second Look

by Michael Robinson

Yes, you are currently reading the follow-up on networks of neurons and your neural net is making you do it! Last February, we discussed a common type of neural net that may very well emulate our own, human neural nets. This time, I'd like to look at another type of common neural net whose structure is also very close to that of our own and give you some ideas to chew on. What could be a better way to start our follow-up than with our very own recap?

Our last neural net was a small combination of consecutive switches with multiple different threshold values. When we applied a voltage to the first "neuron" or switch, it would filter out any input less than its threshold value, while allowing any voltage equal to or greater than this magic value to pass. By linking a large number of these neurons together — or even a small number, as in our example — a neural net was formed. As most of you probably remember, a neural net is a form of AI (Artificial Intelligence) based upon the modular structure of the human brain.

The Human Brain Reloaded

In the minds of our teachers and students, the brain can actually take on many forms, as its precise, low level structure is still very misunderstood by us. We don't know for sure that our brain is based on many different threshold values, yet we also don't know for certain whether the new structure I'm about to discuss holds any truer. With that notion in mind, let me delve into this new and more practical structure that we'll call NeuralNetR.

In NeuralNetR, there is no change in voltage among signals, each and every signal is either -50 mV or 0. This setup very closely emulates that of binary and could, in fact, be considered identical. I know what's on your mind now — why is -50 mV used for the on state? Well, I'll rebut that with this — why is 5 V used for most common integrated circuits?

The voltage of any sort of logic relies almost entirely upon its implementation. Neurons are turned on and off through the occurrence of chemical reactions that occur exclusively along the neurons' dendrites. In review, dendrites are the neuron's receptors — or "input pins." As long as the logic understands its own implementation, in theory, everything works flawlessly.

So, how does NeuralNetR actually implement logic if all of its neurons are identical replicas? NeuralNetR was smarter than the average neural net and — rather than being overly complicated by modifying each threshold value — it modifies its neural network connection pattern. NeuralNetR uses its neurons in a similar fashion to OR gates.

As we astute electronics hobbyists know, OR gates will forward the input signal as long as it meets the OR gate's data sheet's specified internal threshold value or — in the case of our brain — as long as they meet the neurons -50 mV threshold.

Using a neural structure like this, your brain is converting one or more input signals into one or more output signals of the same magnitude (voltage). This setup allows multiple inputs to trigger one output and one input to trigger multiple outputs (in Figure 1, left is the input neurons, right is the outputs).

This proves to be extremely useful for forwarding our body's inputs to appropriate analyzers and even to the appropriate muscles without running a separate neuron for each input. Hence, the name neural network — just as multiple computers run and communicate on a computer network, multiple input and output neurons run and communicate in a neural network. If our nervous signals didn't utilize common paths, we'd all just be a big clump of tangled neurons with no room for any other essential organs in

our comparatively small bodies.

Neurons At Your Defense

As you might have guessed already, your neural net's main purpose is to logically forward all incoming signals to a higher authority that contains an even more advanced structure of neural nets. This higher authority is your cerebrum — the consciousness of your brain — and even the best scientists still have no idea how this section of the brain allows a human to think and analyze such intricate data. It is unknown even to you what composes your mental mind. The closest hobbyists can get to replicating the decision making ability of a person is through the development of neural nets, many of which are very similar to the two I've just described.

It may come as a relief to you to hear this, but not all nervous signals must travel through your brain. In fact, the human nervous system's signal paths that we're most interested in resemble almost identically the pattern of NeuralNetR; you may know these as reflexes. Reflexes are implemented within your body as reflex arcs. A reflex arc is a path through which nervous signals can travel directly from input to output. Reflexes are one of many safety mechanisms in our body; many of these are overly complicated and unrelated to neural nets and won't be covered here.

Reflexes allow your body to remove itself from danger without the large overhead time needed by your brain to determine what should be done. Let's go through a scenario in our mind to display the usefulness and function of reflex arcs: You turn on your stove and, while it's heating up, you reach for a can and accidentally touch your hand to the element. Your hand jumps off of the element and you've witnessed reflexes.

Again, you're thinking that this is real great and all, but how does this help me build a neural net? Well, I'm glad you asked that question because, after neurons themselves, reflexes are the most essential concept in developing a hardware-based neural net. We have to admit that, if we're reading an article in *SERVO Magazine* entailing logic gate-based neural nets, we're probably interested in building one for a robotic project. In any type of robot, the primary concern is to quickly and correctly act upon a certain input — a concept strikingly similar to the concept of your reflexes.

What Does It All Mean?

Before the age of the microcontroller, all robots were based on simple neural nets that were very similar in concept, but even simpler than NeuralNetR. After the advent of the microcontroller, it became more practical to code artificial software neural nets into microcontrollers through the use of simple IF/THEN commands.

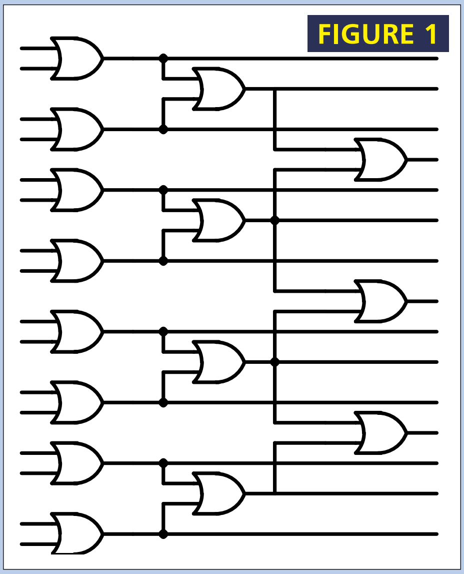
Just as NeuralNetR would output a few small voltages based on an input or two by using some logic chips, microcontrollers would do this with a single chip and two lines of code. As you might expect, the use of static neural nets decreased as dynamic code could be used. Lately, however — out of enthusiasm to create a machine that emulates the human mind as closely as possible — neural nets have posed an interesting challenge and gained greater popularity.

With a few OR gates, we can wire a digital sensor input to a digital motor output, along with many other I/O devices, and have only the appropriate motors run when the appropriate sensors receive an appropriate signal. Although it may not be as efficient or practical as a microcontroller, we're correctly emulating the reflex arcs of the body's neural net.

One major advantage that neural nets have over their microcontroller counter parts is reaction speed. Just as reflexes in your neural net are faster than your brain at analyzing the data, your electronic neural net is faster than a microcontroller at analyzing the data. This makes NeuralNetR great for any project you might have that requires lightning-fast reaction time.

Despite their differences, neural nets and microcontrollers don't have to be mutually exclusive. Just as your body combines your cerebrum with your neural net, you can combine a microcontroller with a NeuralNetR. Combinations like this can lead to very interesting results that even more closely mimic the human nervous system.

FIGURE 1



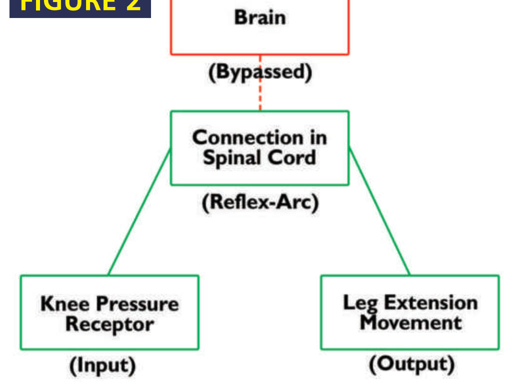
For example, in your design, you could have your microcontroller analyze all of your data while having your neural net perform speed critical reflex-like operations — such as cutting the power to the motor if your robot is about to drive off of a cliff.

I hope you enjoyed this follow-up to our first discussion of neural nets and that — in addition to providing some useful information to your knowledge base — it also inspired you to try integrating a neural net into your next robotics project.

For more information on neural nets, check your favorite search engine and the comp.ai.neural-nets group at **http://groups.google.com** I'll post all errata, updates, and follow-ups relating to any of my neural net articles at **www.fuzzymuzzle.com** so be sure to check it out if you find anything quirky. If you have any questions, comments, or suggestions, please feel free to Email me.

In the meantime, be on the watch for opportunities to implement neural nets in your robotics projects. SV

FIGURE 2



A BEAM Technology

by Jason Travis

To envision life on a pile of metal, silicon, wires, gizmos, and widgets has been the dream of many people — from the ancient Greek writers' legends of giant metal men to George Lucas' sci-fi saga. Thanks to current pioneers — such as Mark Tilden and Rodney Brooks (among others) — we are getting closer to achieving this lofty goal.

In the last few years, we have seen artificial life, chaos theory, and BEAM Robotics[1] actually become legitimate sciences. In the new field of Artificial Life (known as A-Life), biological behaviors — such as emergence, evolution, and flocking — appear in non-living entities[2]. We have seen the classical notion of artificial intelligence give way to neural networks, fuzzy logic, and emotional robot heads, like Kizmet[3]. Nowhere is this exciting evolution more raw and passionate than in the science of BEAM robotics, but — like most robotics fields — BEAM is in its infancy. In BEAM's present state, there are limitations — or are there?

Most BEAM roboticists study a creature and its effects on its environment using a minimalist analog approach. In fact, attempts have already been made to establish rules of behavior, such as Mark Tilden's Laws of Robotics, found in *Junkbots, Bugbots, & Bots on Wheels*:

1. A robot must protect its existence at all costs.

2. A robot must obtain and maintain access to a power source.

3. A robot must continually search for better power sources.

Startling work pertaining to emergent behavior has shown success, even though these creatures are still fairly basic in the behaviors they exhibit. It is impressive that a robot — such as Mark Tilden's Walkman — can navigate over the desert terrain around Santa Fe, NM. This is a task that robots from universities all over the world find difficult — even impossible — without huge amounts of computing overhead. Walkman does it with a couple of ICs, resistors, and basic circuits, all used in unconventional combinations. When faced with an obstacle, the Walkman either powers over it by warping its leg and body or backs up and heads in a new direction.

All this has happened while the traditional university mobot is still determining the type of terrain and calculating the best course. However, while BEAM bots excel at crossing terrain, they cannot report back to base what they see, as the Mars Rovers do. BEAM bots are good at instinct, but they are not that good at thinking; they are akin to insects and bacteria in this regard.

The point of all this is to stimulate and prepare the robotics community for Phase II of the BEAM evolution: the coming of BEAM ecology. We are going to build an ecosystem in our minds. Maybe one or more of us might choose to extend this into the real world and build a living ecosystem. This would, of course, entail mostly the use of the biology aspect of BEAM. What I am proposing is a fusing of the world of BEAM and the world of A-Life. As the lines blur here, I will leave it to the reader to differentiate between real and artificial, living and non-living. Beware — beyond these edges, there be dragons.

Earlier, I mentioned Tilden's Law Number One: Protect thyself. What if, in this ecosystem, some of our BEAM bots could protect themselves? How about hard-wiring in the concept of live, don't die? Put into biological terms, this is known as fight or flight. Any student of BEAM technology has heard the one about the cat getting hold of a legged BEAM Walker, mangling it, and, yet, it still walks. This is a testament to the robust nature of such a bot. What about arming a BEAM robot? We already do it in robot wars, games, and even sumo. How about a BEAM robot with a stinger — say a whipping tail with an electromagnetic disrupter? How about a robot with a strong jaw and saw-like teeth to bite with in a confrontation?

Let's take an evolutionary view of our ecosystem. If a bot's batteries die and it cannot get to a recharger, do we take it out of the world? Should we leave it there to decompose? What if the bot's solar cell becomes disconnected; do we repair it? I suggest the answer is leave it.

After all, when we die in this world, we aren't reanimated any more than a deer is when it dies. These are ideas that are unique to a closed ecosystem: ideas such as old age, other competitive creatures, predators, natural obstacles, diseases, and even starvation.

How about reproduction? Okay, I know what you're thinking — we can't even get a robot to build a copy of itself, let alone reproduce (with the exception being a couple of Japanese automated factories that build robots, but they still require human interaction). Therefore — as is sometimes necessary — we will make an exception to the

definition of reproduction. We will use external introduction to substitute for reproduction.

There are many examples in nature of non-sexual reproduction. Asexual reproduction is a good example, as is the invasion of non-indigenous species into a fixed ecosystem, causing crossbreeding. What if we add a new BEAM creation into our ecosystem every month? Now a "new" bot is born from the perspective of that world.

How would it affect the existing bots? What about surrogate mothers? What if we produce a weird bit of hybrid behavior between two robots? One robot is the surrogate mother who waits for the "baby" to arrive. When you introduce the baby into the new world, it doesn't have any power. The mother bot has to pick up the baby bot and carry it to a power station to feed it — kind of like nursing.

In nature, there are a few creatures that even use community nursing. Another take could be that the baby has a limited amount of power when born and has to cannibalize power from the mother bot, who willingly gives up her life for the newborn. In nature, some insects also eat their birth mothers' bodies for nourishment.

This brings us to the concept of death. BEAM robots do have a limited age; motors wear out, electronics short out, and legs mangle to the point of no return. If a robot runs out of energy and cannot regenerate it, it is dead. For example, a phototropic robot could die if trapped under an artificial plant; it runs out of power and is never again able to obtain sunlight. A recharger bot — despite being hard-wired to seek out a recharger — never makes it to one. A predator bot can rip out the electronic guts of an herbivore bot. Alternately, a predator can eat all the energy in another bot's power pack. Imagine a BEAM predator that is designed to seek out another bot and suck the volts right out of it.

That brings us to Rule Number Two: Feed thyself. I briefly teased you with the idea of an herbivore. How about roaming herbivores that feed off plants? That brings to mind a very specialized type of BEAM robot — the BEAM plant. This would be a semi-stationary bot whose only movement would be to

References

1 BEAM — Stands for Biology, Electronics, Aesthetics, Mechanics. Biology means to make it comparable to nature in function and design. Electronics is short for running with basic analog and digital circuits to imitate animal reflexes, rather than using computer brains. Aesthetics, in essence, means make it pretty, not just functional. Mechanics means to make it functional; do more with less, so that emergent behavior comes out of wire and rods.

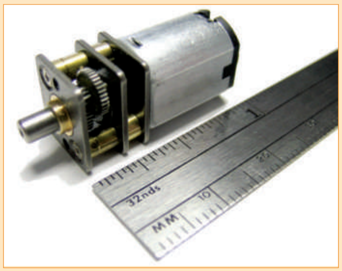
2 See Larry Yaeger's Polyworld at **http://homepage.mac.com/larryy/larryy/PolyWorld.html** or the International Society of Artificial Life at **www.alife.org**

3 See the Robot Kizmet at his MIT website: **www.ai.mit.edu/projects/humanoid-robotics-group/kismet/kismet.html**

(continued from Page 34)

MOTORS

12 mm Gear Motors for Robotics and Mini Appliances



SANYO DC Micro Motor Division introduces the 12GN Series, a new line of 12 mm geared DC micro motors. Ideal for robotics and compact applications, these high torque motors offer designers a space saving alternative to much larger brush motors. The 12GN motor measures only 12 x 10 x 29 mm from terminals to tip of shaft and weighs 8.7 gr. Starting torque is 300 mN·m. Rated load is 20 mN·m.

Operation is quiet due to the close tolerance precision of the shaft rotation. In addition to robotics and mini appliances, other applications include power tools, locks, medical and dispensing equipment, and mini printers. Depending on model and features, the price of a 12GN gear motor is less than $3.00 in volumes of 100K and above. SANYO also offers an extensive product range of vibrator, precious metal brush, brushless, and stepper micro motors in OEM quantities.

SANYO 12N gear motors are available with a choice of four gear ratios. Model NA1S has a gear ratio of 1/75.7, model NA2S is 1/134.5, model NA3S is 1/196.6, and model NA4S is 1/297. Motors with limiters are also available.

No-load speed ranges from 62 to 246 RPM, depending on model. No-load current is 120 mA. Endplay is 0.02 to 0.35 mm in the drive shaft. Lateral play is less than 0.04 mm at the tip of the drive shaft. Vibration is less than 40 m/s^2. Noise is below 55 dB at 5.0 V. Operating temperature range is 0° C to +50° C, but there is reduced life expectancy in colder environments.

Gear motors as small as 8 and 10 mm are expected to be introduced in late 2004.

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point to a source of light or the sun. Once oriented so, the plant would open its leaves to fully expose solar panels to light. In its base, large capacitors would charge up and store voltage — its food. On its base, "scent" modules would attract herbivores to it for feeding.

Herbivores — being bigger and slower, as in nature — would allow for attack by the faster predators. However, this is where "herding" would come in. The predator may get the closest herbivore, but would be hard-pressed to get the three behind it. Could an herbivore also sense a predator and flee? Could a predator smell a BEAM bot it considers to be prey? This gets into a built-in instinct system more complex than basic BEAM walking instinct, but — if we applied other robotic concepts, such as subsumptive behavior — we could create instinct and still not have to use a microcontroller or processor.

The first precept of being a carnivore is eating other creatures. This implies having a mouth, which — on many BEAM bots — has been sorely missing. With jaws, a predator could effectively rip, tear, or crush its intended prey, not unlike a lion grabbing the throat of larger prey to bring it down. Now, the predator could search the disabled bot for food — i.e., an energy source. Mandibles could directly attach to a creature's power source and suck it out with a sucker bite — like a mosquito or a spider.

The predator would, of course, be lighter and faster, but would have to feed quickly and often to prevent losing power. This would create a feeding instinct.

Predators would also have to scout out herbivore prey — which might have their own defenses. Ambush might be the tactic of the day, so predators and herbivores would both have individual scents. This way, predators would avoid each other or possibly engage in territorial disputes. This could be done with frequency bursts. Scents could be represented by different colored LEDs (Light Emitting Diodes). Herbivore bots could even engage in camouflage techniques, such as hiding behind a recharger plant to mask its LED scent from any would-be predators.

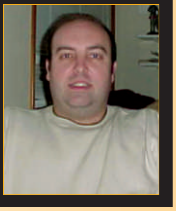
Finally, let's consider the ecosystem itself. What would be the life span? At some point, would you permanently turn off the light source and start over? How about daylight versus nighttime cycles? Would you have nocturnal bots and diurnal bots? How would they coexist?

You could add weather to the ecosystem — fans to provide wind or humidifiers to provide fog. You could have water obstacles with shallow points that must be crossed by land walkers. This brings to mind water creatures — a whole other breed of BEAM technology: BEAM fish, eels, and crocodiles. Then, of course, some unwary bots might drown. You could add complexity to the system's circle of life with some plants that yield more electricity then others — even poisonous plants. This would be true survival of the fittest.

There is already work being done on large BEAM zoos and displays, but there is room to kick it up a notch. The only limits are imagination, time, and money. Then again, aren't those the same demons that roboticists face on a regular basis? **SV**

Author Bio

Jason Travis is an active member of the Seattle Robotics Society. He works in Business Administration and is seeking a career change into electronic engineering. His hobbies include robotics, AI, A-Life, and playing jazz on the saxophone.



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